Ancient and Modern Ships

BY

SIR GEORGE C. V. HOLMES, K.C.V.O., C.B.

VICTOR[illegible]

Fig. 1. The *Carmania.* 1905.

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ANCIENT AND MODERN SHIPS.

PART II.

THE ERA OF STEAM, IRON & STEEL.

BY
SIR GEORGE C. V. HOLMES, K.C.V.O., C.B.,
HON. MEMBER I.N.A., WHITWORTH SCHOLAR.
FORMERLY SECRETARY OF THE INSTITUTION OF NAVAL ARCHITECTS.

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PREFACE.

THE production of the first volume of this handbook was rendered difficult by the scantiness of trustworthy records. A similar remark applies to the first chapter of the present volume, which deals with the history of the earliest days of steam navigation. On the other hand, in writing the remainder of the book, the difficulty has rather been to select from the superabundance of available material. Limits of space have rendered it necessary to reject a great deal, and that which has been selected is only what appeared to be essential for the purpose of putting before the reader a history, in outline, of the development of modern ships.

This volume is, in the main, devoted to mercantile ships. The man-of-war, considered as a fighting machine, has not been touched; in fact war vessels have only been alluded to when the introduction of peculiarities in their construction seriously influenced the development of shipbuilding. The evolution of the war ship as a fighting machine, from the time of the introduction of steam down to the present day, affords abundant material for a separate work.

A large part of the book has, necessarily, been devoted to a description of steamships that have, at one time or another, played, or that are actually playing, an important rôle in the history of navigation, and, possibly, the chapters

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dealing with this part of the subject will prove to be those that interest general readers the most; but, in the hope that the book may be of some little use to professional students, I have endeavoured to give an account of the reasons which have led to the introduction of new materials, of novel methods of construction, and of different varieties of types of merchant vessels. As far as I am aware, the sketch of the development of the structural features of iron and steel ships is the first attempt that has ever been made to give a connected account of this subject from the historical point of view.

This volume is not a history of steam navigation, nor is it a treatise on shipbuilding and naval architecture. Its primary purpose is to enable students and others who visit the collection of ship models at South Kensington to understand more fully what they see, and at the same time to supplement, as far as possible, the contents of the museum, so as to form with them a fairly continuous account of the progress of steamship building down to the present time.

There are many branches of naval architecture, such as the theory of stability and of the resistance of ships, which can only be studied in scientific treatises, and in the illustration of which museums can be of but limited use. On these I have not touched. The structure of ships, however, stands in a different category. It is a subject eminently suited for illustration in a museum, and therefore I have not hesitated to devote considerable space in the body of the book to the physical side of the question; while, in order to help students I have added an Appendix on the external forces which act on ships, and the stresses that they produce, to meet which the structural arrangements are devised.

A second Appendix is added on a subject which has always exercised a considerable influence on the design of steamers, viz.: tonnage measurement. It gives a sketch of the history

of this subject, from the time of its application to sailing ships down to the present day.

The third Appendix is a tabular statement of the principal dimensions and other particulars of some notable Transatlantic steamers between the years 1837 and 1906.

I am indebted to many sources for the information contained in this volume, especially so to the Transactions of the Institution of Naval Architects, of the Institution of Civil Engineers, of the Institution of Mechanical Engineers, and of the North East Coast Institution of Engineers and Shipbuilders. Amongst many other works which I have consulted I may particularly mention "Naval Science," the "History of Merchant Shipping and Ancient Commerce," by Mr. W. S. Lindsay; the "History of Steam Navigation," by Mr. J. Kennedy; the "Life of Robert Napier," by Mr. James Napier; the pages of "Engineering," the "Engineer," and the "Illustrated London News," the large work on Naval Architecture by the late Mr. J. Scott Russell, and the well-known work of Sir William White. The illustrations also are largely drawn from these sources. Some of them are reproduced from old prints and pictures, and for others I have to thank the Committee of Lloyd's Registry, Messrs. Harland and Wolff, the City of Dublin Steam Packet Company, Ltd., the City of Cork Steamship Company, Ltd., Messrs. William Doxford and Sons, and Sir Raylton Dixon and Co., Ltd., and the North German Lloyd Steamship Co.

Early in the year 1901 a change of avocation largely reduced my facilities for working at this volume. I am greatly indebted to Mr. G. R. Dunell for valuable assistance rendered to me in the difficult circumstances which then arose.

DUBLIN. *July*, 1906.

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ANCIENT AND MODERN SHIPS.

ERRATA.

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"	145,	"	2,	" top,	"	"just eighteen"	"	"over nineteen"
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Appendix III. "stroke" column line 2 from bottom, delete "66."

power was reduced and the economic employment of steam ships on longer voyages became possible. For many years the sailing clippers held their own on the longest passages, as for instance, to the far East, to Australia and the West Coast of the American Continent. The application of the compound

engine to marine purposes in 1856, resulting as it did in a great reduction in fuel expenditure, and the opening of the Suez Canal in 1869, which enormously shortened the route to India, the Far East and Australia, were the final causes which brought about the practical supersession of the sailing clippers. The word "practical" is used because even to this day great sailing ships are used for special purposes in certain trades. They are, however, no longer built of wood as in the middle of the last century. As their size increased the problem of providing sufficient structural strength with timber alone became more and more difficult. In 1851 the so-called composite system of construction was introduced, the framework having been made of iron and the planking of wood. The first composite seagoing vessel was the *Tubal Cain* of 787 tons, built at Liverpool by Mr. Jordan. The system was, however, invented about the year 1839 by Mr. Watson of Dublin. Many fine clipper ships were built on this method, but it soon gave way to a system of all iron and, ultimately, to all steel. The development of these latter modes of construction is fully described in Chapter VII. At the present time the competition of large sailing ships with steamers is mainly rendered possible by the system of bounties in vogue in certain foreign countries.

The application of steam to ocean transport was one of the principal achievements of the nineteenth century. It is hardly possible to over-estimate the importance of the rôle which it has played in the development of commerce and of civilization. Freights are now a mere fraction of what they were in the era of sailing ships. Services can be carried on with the utmost regularity to and from the most distant parts of the earth independently of the influence of the weather, and the time occupied on voyages has been reduced practically from weeks to days. In the palmy days of clipper

ships a rapid journey from Shanghai to London occupied 70 days while an ordinary voyage ran to 100 days. Nowadays the mail steamers of the Peninsular and Oriental Steamship Company do the distance regularly in about 35 days. Before the introduction of steamships on the Transatlantic service a voyage from New York to Liverpool under the most favourable circumstances lasted for 13 days, an ordinary journey took 21 days,* while to-day the fastest steamships of the great companies cross from Queenstown to New York in about $5\frac{1}{2}$ to $5\frac{3}{4}$ days, and record journeys have occupied as short a time as $5\frac{1}{3}$ days.

The early history of the application of steam to marine propulsion is to be found in the "Handbook on Marine Engines and Boilers."† It was there shown that Messrs. Miller & Symington made the first really conclusive practical experiment on Dalswinton Loch in the South of Scotland in 1788, and that in the following year a second steam vessel was successfully tried by them on the Forth and Clyde Canal. Nothing further was done for a decade, but about the commencement of the last century Symington was employed by Lord Dundas to build for him a steam tug for use on the above-mentioned canal, and in the early part of 1802 he successfully tried the *Charlotte Dundas*, the propelling machinery of which was a long way in advance of the time, inasmuch as it consisted of a stern wheel driven by the first horizontal direct-acting engine that was ever constructed. It was also shown that an unsuccessful attempt had been made to propel a vessel by steam in the year 1797 by Chancellor

* In 1862 the clipper ship *Dreadnought*, 1,413 tons, sailed from Sandy Hook (New York) to Queenstown in the extraordinarily short time of 9 days 17 hours.

† Victoria and Albert Museum Science Handbooks: Marine Engines and Boilers, by the present Author.

Livingstone of the United States, assisted by the famous Mark Isambard Brunel, and that in 1803 the same Livingstone, working with the afterwards celebrated Robert Fulton, made two unsuccessful experiments on the River Seine. Fulton, in company with Henry Bell, who afterwards owned the *Comet*, then visited Symington, witnessed a trial trip of the *Charlotte Dundas* and obtained the information of which he had need and which he was afterwards destined to turn to such excellent account. Fulton in 1803 entered into negotiations with the famous English firm of Boulton & Watt, of Soho, Birmingham, who were the greatest engine builders of the time,* and obtained from them the main working parts of a trial engine which were delivered in the United States in 1806, fitted in the following year into the ever-famous boat, the *Clermont*, and proved a practical success, as this vessel was run under steam for some time on the Hudson River between New York and Albany. Copies of the original drawings of this engine and of the correspondence between Fulton and the firm of Boulton & Watt are published in the Transactions of the Institution of Naval Architects, vol. xl. p. 110 and Plate xxvi.a.

The *Clermont*, an illustration of which is shown in Fig. 2, was completed in 1807. She was 133 ft. long and 18 ft. wide, with 9 ft. depth of hold. She ran from New York to Albany, a distance of about 150 miles, in thirty-two hours, and returned in thirty hours. She afterwards was advertised as making regular trips between New York and Albany. The *Clermont* was the pioneer of that magnificent steam boat service ultimately established on the inland waters of the United States of America.

* Fulton had been previously in communication with Messrs. Boulton & Watt in the year 1794, but the negotiations apparently led to nothing.

Fig. 2.—The *Clermont*. 1807.

It should be mentioned here that many inventors before the time of Miller & Symington are said to have turned their attention to the application of steam to marine propulsion. Everybody has heard the names of Papin, Jonathan Hulls, the Marquis de Jouffroy, but their inventions have either not been described, or have been followed by no results. It is known that while Fulton was making his early studies in Europe, his countryman John Fitch was experimenting in the neighbourhood of Philadelphia. Nothing is now known of the nature of his propelling machinery, but there is extant a copy of the *Federal Gazette and Philadelphia Daily Advertiser* of the 26th July 1790 in which there is an advertisement of the sailing of a steam-boat from "Arch Street Ferry in order to take passengers for Burlington, Bristol, Berdentown and Trenton and return next day." This may possibly have been Fitch's boat. We know nothing of its dimensions, machinery, or later history, and the experiment had no influence upon the subsequent development of steam navigation. All reliable records point to the fact that the true history of the evolution of the marine engine originated with the work of Miller & Symington. It was their experience that rendered possible the subsequent success of Fulton and his compatriot John Stevens, to whom the invention owes a great deal of its early development.

It must be pointed out that Fulton was not the only successful American pioneer in steam navigation. John Stevens is recorded to have, in the early years of the last century, "succeeded in practically applying steam to the propeller." The original engine, which he designed and constructed in 1804, was the first steam engine to drive a screw propeller successfully. It is preserved in the Museum of the Stevens Institute at Hoboken, New Jersey. In that year (1804), his boat, propelled by

twin screws geared to a steam engine, was driven from the battery in New York across the Hudson River to Castle Point, Hoboken, at a speed of six miles an hour. The screw propeller, like the paddle wheel, was a very old invention, but John Stevens appears to have been the first to apply it in conjunction with a steam engine to ship propulsion. The experiment could not, however, have been attended with much success, for 32 years were allowed to elapse before another serious effort was made, this time by Pettit Smith and Ericsson, to turn the screw to account as a propeller. A second steamer named the *Phœnix* was built by Robert L. Stevens in conjunction with his father John Stevens. In 1808 this vessel went round from New York to Philadelphia by sea and afterwards ran on the Delaware River. The late Mr. J. Scott Russell, alluding to this event, said that Mr. Robert L. Stevens was "undoubtedly the pioneer of steam navigation in the open sea." Scott Russell indeed awarded to Stevens higher credit even than to Fulton; for he said, "Robert L. Stevens is probably the man to whom, of all others, America owes the greatest share of its present highly improved steam navigation."

These early successes set men thinking in all parts of the world; for, though the appliances were rude compared with what we see in the present day, and the engines were wasteful of fuel, yet to make a large vessel travel in the wind's eye was then hardly less a marvel than was the mechanical propulsion of coaches of over a quarter of a century later. On the North American continent, enterprise was quickly stirred. In 1809, the *Accommodation*, the first steam-boat on the St. Lawrence, was launched, another following two years later. In 1811, the *New Orleans* was constructed at Pittsburg for service on western waters. In 1813 two new steamers, the *Swiftsure* and the *Car of Commerce* plied on the

Fig. 3.—The *Comet*. 1811.

St. Lawrence. The former of these was 140 ft. long over all and 24 ft. in breadth. In 1814, the *Fulton*, the first war steamer, designed by Fulton, was built at Brown's shipyard in New York. In 1816, eight steamers had been built to run on the Hudson, and five or six on the Delaware. In 1817, the first steam boat ran from New York to Newport, and the same year the first steam vessel was put in service in Boston Harbour. In 1818, steam navigation was inaugurated on Lake Erie.* In 1823 it is said that 300 steamers were at work on American waters.

Returning now to our own country. Four years after the *Clermont* was built in America a steam boat passenger service was inaugurated in Great Britain on the Clyde, which river was the cradle of steam navigation in European waters, and still maintains its ancient prestige as being the most renowned centre of shipbuilding industry in the world. In the year 1811 the *Comet* (Figs. 3 and 12) was built on the Clyde by J. & C. Wood to the order of Henry Bell, the proprietor of an hotel. She was smaller than the *Clermont*, having been 40 ft. long on the keel, 10½ ft. wide, and of about 25 tons. The machinery was constructed by John Robertson, of Glasgow. The engine of this historic craft is happily still preserved, being in the Victoria and Albert Museum. It is illustrated and described in the "Handbook on Marine Engines and Boilers," pp. 20 and 21. The *Comet* made her first voyage in January, 1812, and plied regularly between Glasgow and Greenock, at about five miles an hour. She was a side wheel boat and had originally four paddle wheels. Two of these were removed and, as can well be understood, the change led to an improvement in speed.

* *See* report of the United States National Museum for 1890, on which authority most of the details relating to American vessels are given.

Another steamer named the *Elizabeth* was launched on the Clyde in 1813. She was larger than the *Comet*, having been 58 feet long over all, and 11 ft. broad. She plied regularly twice a day between Glasgow and Greenock. During the next year (1814), five steamers are recorded as running on the Clyde. One of these, the name of which has been lost, was sent round in June, 1815, to the Mersey, and was the pioneer of steam navigation on that river. Another was named the *Industry*, and a third, the *Argyle*, is described below, and it appears that ten in all had been turned out with success. Up to this time, no steamer is recorded to have been at work on the Thames; although one which had plied between Bath and Bristol was sent round later by inland navigation, but was driven away by the opposition of the Thames watermen.

The first regular passenger steamers on the Thames were the *Marjory*, the *Defiance* and the *Thames*. The *Marjory* was built at Glasgow and sent round in 1815, when she ran daily, once up and once down, between London and Gravesend. She measured 70 tons and had a fourteen horse-power nominal engine. During the same year the *Argyle*, another wooden steamer by the same builders, J. & C. Wood, came to the Thames from the Clyde. She was 74 tons burthen, 65 ft. long on the keel, 14½ ft. wide, and had a draught of water of 3½ ft.* Her paddlewheels, 9 ft. in diameter, 4 ft. wide, and with six floats in each, 15 in. broad, were driven by a nominal sixteen horse-power engine, the speed averaging 7 miles an hour. She was re-christened the *Thames*, and plied between London and Margate. Her adventurous

* According to another authority the *Argyle* was of 70 tons register, 79 feet on the keel, 16 feet beam and of 14 nominal horse-power. On the day of her arrival in the Thames she steamed up the river from Margate to Limehouse, a distance of 90 miles, at the rate of 10 miles an hour.

Fig. 4.—Clyde passenger steamer of 1817.

Fig. 5.—Thames passenger steamer of 1819.

voyage from the Clyde to London waters is described in *Chambers's Journal* of April 25, 1857.

In 1816, another of Messrs. Woods' steamers, the *Caledonia*, was brought from the Clyde to the Thames. She was 94 ft. long and 15¼ feet wide. She had two engines of thirty-two nominal horse-power, collectively, said to have been built by Boulton & Watt. Mr. James Watt, Jnr., purchased her and, after she had been fitted with new machinery, took her from Margate to Rotterdam, and from thence to Coblentz in 1817. She is said to have been the first steamer on the Rhine and also the first to to have crossed the English Channel, but there are grounds for believing that she was preceded in the year 1816 by another British steamer. She was afterwards sold to the King of Denmark. In 1817, Elias Evans of Frindsbury, near Rochester, launched the *Sons of Commerce*, a steamer 85 ft. long by 25¼ ft. wide. The engines, of twenty horse-power nominal, were constructed by Boulton & Watt. She was followed by the *Favorite*, the *London*, and the *Diana*, and by a vessel named the *Victory*, which plied to Margate, together with the *Favorite*, in 1818. During the same year Napier, of Glasgow, engined a sea-going steamer, the *Rob Roy*, of about 90 tons and 30 nominal horse-power. She ran regularly between Greenock and Belfast, and afterwards between Dover and Calais. This vessel was constructed by William Denny, the founder of the well-known firm of ship-builders, at Dumbarton.

Steam communication between Great Britain and Ireland was established in the year 1816, when the *Hibernia* was built to run between Holyhead and the Royal Harbour of Howth, which was at that time the port at which mails and passengers for Dublin were landed. The *Hibernia* was 77 ft.

along the keel, of 9 ft. draught, and of 112 tons burthen. She was the pioneer of the principal cross-channel service in the British Isles.

In the year 1819 the first attempt to cross the ocean was made in a ship carrying an auxiliary engine. It must, however, be noted that only a small part of the voyage was made with the aid of steam. The vessel in question, named the *Savannah*, was of American build. She may justly be described as an experiment, for, as a steamer, she never earned a shilling for her proprietors, either by carrying freight or passengers. In a monograph, contributed by Mr. J. Elfreth Watkins, Curator to the Section of Transportation and Engineering in the Smithsonian Institution at Washington, and republished by the United States Government Printing Office, the facts relating to this vessel have been brought together.

Fig. 6 is an illustration of the *Savannah* taken from a corrected drawing by C. B. Hudson, made under the direction of Captain J. W. Collins of the United States Fish Commission, and is reproduced through the courtesy of the United States National Museum. As will be seen, the vessel was a full-rigged ship, and was of 350 tons burthen. She was built at New York by Francis Fickett in 1818, having been originally designed as a sailing vessel. At the suggestion of Moses Rogers, who had been associated with Fulton and Stevens when commanding some of the early steam-boats, Messrs. Scarborough & Isaacs, shipowners, of Savannah, purchased the vessel on the stocks and had her fitted with an inclined direct-acting, low-pressure engine of ninety horse-power, the diameter of the cylinder having been 40 inches and the stroke 5 ft.

This interesting engine was constructed in America by Stephen Vail, of Morristown, New Jersey; the boilers

FIG. 6.—The *Savannah*, 1818.

The voyage lasted twenty-nine days eleven hours, and during that time steam was raised on six occasions, and used for eighty hours out of the seven hundred and seven. This time of steaming is taken from an extract from the log kept by Stevens Rogers, the sailing master, a document now in the United States National Museum. The fact is worth noting, as it was said in an English newspaper that "during her passage she worked the engine eighteen days;" a misstatement that has been more than once quoted. Stevens Rogers himself made a declaration thirty-seven years later that the vessel was fourteen days under steam. His log, written at the time, must, however, be taken as better evidence than his memory. It has also been said that the *Savannah* arrived laden with cotton and passengers; this hardly agrees with the statement of Mr. Watkins that "the *Savannah* never carried a single passenger, or pound of freight for pay while she was a steam-ship." Mr. Watkins is, no doubt, a better authority than the newspaper which contained the former assertion.

Although the *Savannah* was but eighty hours under steam she had consumed all her fuel by the time she arrived off Cork, as she could not use her engines owing to there being "no coal to get up steam." In the particulars of the vessel it was said that she carried seventy-five tons of coal and twenty-five cords of wood; but whether, or no, this was the amount with which she was laden on starting from America is not stated. She appears to have replenished her supply, for she is reported to have "entered the harbour of Liverpool under bare poles, belching forth smoke, yet uninjured."

Probably a good deal that has been reported of the *Savannah* is legendary. The fact remains, however, that an American-built ship, engined by Americans, and owned by Americans, crossed the Atlantic in the year 1819; as, however, the

greater part of the voyage was made under sail, doubtless with the paddle wheels on deck, the claim that this was a steam voyage across the Atlantic cannot be sustained.

The *Savannah* did not have a long career as a steamer. She remained in Liverpool twenty-five days, and on the 23rd of July, 1819, she "got under way with a full head·of steam," bound for St. Petersburg and called at Elsinore and Stockholm. The engine was used for a longer time on this trip, the vessel having been under steam about ten days out of thirty-three, and on two occasions the machinery was used for fifty-two hours, whereas eighteen hours was the longest spell when crossing the Atlantic. On the return voyage to Savannah, which was a very stormy one, made during October and November of the same year, the ship steamed out of Cronstadt; the paddle wheels were then taken in, and the engines were not used during any part of the return trip until, on the 30th of November, Captain Rogers steamed up the Savannah river and anchored off the town. During the following December the vessel sailed for Washington, and shortly afterwards her engines were removed and put to other uses. She ran between New York and Savannah as a sailing packet, until, in 1822, she went ashore on Long Island and was broken up.

In 1820 a steamer called the *Conde de Palmella* sailed from Liverpool to the Brazils *viâ* Lisbon, but nothing beyond the fact of the voyage and the name of the vessel are now known. This is the first steamer of which any record exists that crossed the Atlantic from this side.

It was not till many years after the *Savannah* made her voyage to Europe and back that steam communication across the Atlantic was firmly established; but, in the meantime, advance was steadily made in steam propulsion on coasting and inland navigation.

FIG. 8.—The *Isabella Napier*. 1835.

In 1821, Evans built the *Lightning*, the first steam vessel on record to be used for the mail service. She was of 205 tons and 80 nominal horse-power, and was put on the passage between Holyhead and Dublin. During the same year Wigram and Green turned out from their historic shipyard at Blackwall the *City of Edinburgh*, which ran between London and Leith. She had a pair of 80 nominal horse-power engines made by Boulton & Watt. The *James Watt*, Fig. 7, 420 tons, built by J. & C. Wood of Glasgow in the same year, was a notable vessel. She was 141 ft. 9 in. long, 25½ ft. wide, and 16½ ft. deep. She had two engines of 100 nominal horse-power and paddle wheels of 18 ft. diameter.

The first steam-ship voyage to India took place in 1825, when the *Falcon*, of 176 tons, made the run to Calcutta *viâ* the Cape. Like the *Savannah*, the *Falcon* was an auxiliary steamer only, having been rigged as a sailing vessel. During the same year another steamer, the *Enterprise*, 470 tons, and 120 nominal horse-power, built by Messrs. Gordon & Co., of Deptford, made a memorable voyage from England to Calcutta. The time occupied was 113 days, of which 103 days were spent actually under steam, "ten days being consumed for renewals of fuel." Her average speed was 8·79 miles per hour. The *Enterprise* had a length of keel of 122 ft. and a beam of 27 ft.

In or about 1827, the *Curaçoa*, of 400 tons and 100 nominal horse-power, was built in England and sold to the Dutch Government. She is reported to have made the voyage from Helvoetsluis to Surinam in South America, in twenty-seven days and eleven hours. The engines consumed 7·14 lbs. of coal per horse-power per hour.

In 1833 the *Royal William*, of 180 nominal horse-power, built at Quebec by the Quebec and Halifax Steam

Navigation Co., her engines having been made in England by Boulton & Watt, and placed on board at Montreal, made the run from Pictou, Nova Scotia, to Portsmouth, a distance of 2,500 miles, in seventeen days. A considerable portion of this voyage, however, was made under sail alone. The *Royal William* was 176 ft. long over all, by 27 ft. beam and 17 ft. 9 in. depth of hold. Her draught laden was 13 ft.

Fig. 8 gives an excellent idea of the coasting steamer about this period. It represents the Londonderry boat, *Isabella Napier*, built in 1835, and engined by Robert Napier. She was 135 ft. long by 23½ ft. wide, and 350 tons; the nominal horse-power was 220. The illustration is from a painting by W. J. Huggins.

During the whole of this period the types of engines were gradually changing. A record of the principal improvements made is to be found in the "Handbook on Marine Engines and Boilers."

The year 1838 will ever be memorable in the history of steam navigation, as in it were made the first voyages across the Atlantic to New York and Boston, continuously under steam, by the *Sirius*, the *Great Western*, the *Royal William* (the second steamer of that name), and the *Liverpool*. Up to this time, although steamships had passed between Europe and America, not one did so by steam power entirely. Dr. Lardner shortly before this time made the rash statement that one might as well expect to travel from the earth to the moon as to make the voyage from Liverpool to New York by steam alone.

Dr. Lardner may have been right in drawing his conclusion from the experience of the time; his error was that he did not grasp the possibilities for improvement that marine machinery afforded, nor the skill and enterprise of engineers in taking advantage of those possibilities. He

Fig. 9.—The *Sirius*. 1837.

had not, however, long to wait before his predictions were falsified. On the morning of Sunday, the 22nd April, 1838, the steam-ship *Sirius*, Fig. 9, arrived in New York harbour from London, and was followed next day by the *Great Western* which had sailed three days later. The *Sirius* was 700 tons register. She was built by Menzies & Company of Perth for the St. George Company; her engines of 320 horse-power were by T. Wingate & Company of Glasgow. She was 208 feet long over all and 178 feet along the keel, 25 feet beam, and 18 feet depth of hold. She was not built especially for Transatlantic service, having been employed previously in the trade between London (or Bristol) and Cork. The *Sirius* carried ninety-four passengers, and occupied about seventeen days on the trip; the *Great Western* took two days less. On the return journey the *Sirius* was sixteen days, and the *Great Western* fourteen days on the passage. The *Sirius* was chartered for this voyage by the British Queen Steam Navigation Company, whose own steamer the *British Queen*, described below and illustrated on Fig. 13, was not completed in time, owing to the bankruptcy of one of the contractors.

The voyage of the *Great Western*, Fig. 10, was the more important event of the two; for, after her double ocean trip the *Sirius* was put on a station of shorter passages. The *Great Western* was designed and built especially for the Atlantic trade. She was constructed of wood by Patterson of Bristol according to his own design; her extreme length was 236 ft., or 212 ft. between perpendiculars, her breadth 35 ft. 4 in.; or, outside paddle boxes 59 ft. 8 in. Her depth of hold amidships was 23 ft. 2 in. She was 1,321 tons gross, of which about 641 tons were included in the machinery space. Her engines, constructed by Maudslay Sons & Field, of London, were of 450 horse-power nominal, and of 750 horse-power actual,

with cylinders of 73 in. in diameter and 7 ft. stroke. The diameter of the paddle wheels was 28 ft. 9 in. and they made twelve to fifteen revolutions per minute.

The total weight of engines, boilers, and water was 480 tons, the weight of coal for twenty days' consumption, 600 tons, the weight of cargo 250 tons, and the draught of water with the above weights, 16 ft. 8 in.* To enable the ship to resist the action of the heavy Atlantic waves, special pains were taken to give her great longitudinal strength. The ribs were of oak, of scantling equal to that of line-of-battle ships. They were placed close together and were caulked within and without before the planking was put on. The hull was also closely trussed with iron and wooden diagonals and furnished with shelf pieces, while bolts and nuts were used for fastenings to a greater extent than had formerly been the practice. On her voyage out the ship ran 3,125 nautical miles, her average speed having been 208 miles each day or 8·2 miles per hour; the coal consumed was 655 tons. The return passage was made at an average speed of close upon nine knots, at a much smaller consumption of coal, the difference having been due to favourable winds, naturally a more important factor with the lower powered craft of those days than it is now.

The *Great Western* was more than a great engineering triumph, she was a financial success; a fact which did more to establish ocean steam navigation than the barren honour of crossing the Atlantic at a loss to the adventurers, as in the case of the unfortunate owners of the *Savannah*. At a meeting of the proprietors held in Bristol in March 1839, it was stated that "the company's ship had disproved all unfavourable auguries and promptly rewarded the enterprise of the projectors. After having run 35,000 nautical miles

* These figures are taken from a contemporary record. They differ slightly from some since published.

Fig. — The Great Western, 18—

and encountered thirty-six days of heavy gales, her seams required no caulking, and when she was docked she did not show a wrinkle in her copper. The average of her passages out was fifteen and a half days, and home thirteen days. The shortest passage out was fourteen and a half days, and home twelve and a quarter days." A dividend of 9 per cent. in all was paid for the year. She subsequently made some quicker passages, the shortest, outwards, having been twelve days eighteen hours, and the shortest home twelve days ten hours from wharf to wharf, time taken by the chronometer. During the sixth year of her service she was making quicker average voyages than in any of the preceding years. Her total distance run during the six years 1838–43 was 234,000 statute miles, the average speed, outwards, having been 9½ miles, and, homewards, 11½ miles per hour. During the same period the average number of passengers carried per voyage west was ninety and east seventy-nine. The *Great Western* was sold to the Royal Mail Steam Packet Company in 1847, and ten years later was broken up.

The *Royal William*, Fig. 11, was the first steamer to cross the Atlantic between Liverpool and New York. She was owned by the City of Dublin Steam Packet Company then, as now, one of the most enterprising corporations of shipowners. The *Royal William* was built in 1836 for the Irish passenger trade, the main route for which in those days was between Liverpool and Kingstown. The builders of the hull were Messrs. Wilson, and of the engines, Messrs. Fawcett & Preston, both firms of Liverpool. The directors of the owning Company, stimulated no doubt by the success of their neighbours, the St. George Company, with the *Sirius*, contemplated the establishment of a Transatlantic line between Liverpool and New York, and dispatched the *Royal William* as the pioneer steamer early in July 1838. The

voyage took about the same time as that of the *Sirius*, and the return journey occupied fourteen and a half days. The *Royal William* was, however, not suited in design, or size, for the Atlantic trade, and was withdrawn in the year 1839. Her principal dimensions were: length on keel, 175 ft., beam, 27 ft., depth of hold, 17 ft. 6 in. Her engines were of 275 nominal horse-power.

Another notable steamer of this period was the *British Queen*, referred to above. The illustration of this vessel, Fig. 13, is taken from a contemporary print. The hull was built by Curling & Young of London, the engines having been made by Robert Napier of Glasgow. The *British Queen* sailed on her first voyage from Portsmouth on April 2nd, 1839, and arrived at New York on the 16th of the same month. The steam pressure was about 5 lbs. to the square inch and the quantity of coal burnt was 613 tons 16 cwt. Her best average speed for one day was at the rate of 10·2 knots. This vessel was 245 ft. long under deck, or 275 ft. over all, by 40 ft. 6 in. wide, and of 1,862 tons.* Her nominal horse power was 500. The *British Queen* exceeded the *Great Western* in dimensions, and was indeed considered the most magnificent steamer of her day. In a contemporary account her appointments are spoken of with enthusiasm. There was "a spacious saloon or dining-room," the length of which was "upwards of 60 ft., the width 30 ft., and in the narrowest part 20 ft., height to ceiling 8 ft." The ladies' cabin was about 16 ft. square.

It is interesting to compare "the spacious saloon" of 1839 with that of a typical Atlantic liner of the present day, in which the saloon is 108 ft. long by 69 ft. broad and will seat nearly 600 passengers. An idea of the splendour of the modern

* In a Government Report of 1839 the tonnage is given as 2,016. The figure in the list is taken from J. Napier's life of Robert Napier.

Fig. 11.—The *Royal William*. 1836.

saloons is conveyed by Figs. 28, 34, 36 and 40, described at pp. 66, 74, 83 and 88. The *British Queen* cost £60,000. She was barque rigged, and of handsome model, to judge by pictures of her still existing. She was not so successful financially as the *Great Western*, and the enterprise ended in commercial failure.

The soundness of the wooden hull of the *Great Western* has been mentioned and the *British Queen* was also most solidly constructed; but, though the desired end of a seaworthy vessel was thus attained, it was at great expense of money and material. This was beginning to be recognised at the time, and builders looked to iron as a substitute for the material that had held its own for ship construction since the earliest days. The report to the owners of the *Great Western*, to which reference has been made, stated that another ship would be constructed, but that she would be of iron. This vessel was afterwards built and named the *Great Britain*. The question of iron ship building belongs, however, to the following chapter; but, before proceeding to it we must make some reference to a group of ships which did more than others to firmly establish the enterprise of ocean steam navigation, then fairly launched. These vessels were the *Arcadia, Britannia*, Fig. 14, *Caledonia*, and *Columbia*; the first ships of the celebrated Cunard line. They were built by J. &. C. Wood of Glasgow and Greenock and engined by Robert Napier. They were each 206, or 207, feet long between perpendiculars, by 34 to 34½ feet wide, and 1139 to 1,155 tons gross, and 440 to 450 nominal and 740 indicated horse-power. The cylinders were 72 inches in diameter by 6 feet 10 inches stroke. The paddle wheels were 28 feet in diameter. The displacement was about 2,000 tons. The first to be put on the Atlantic station was the *Britannia*, which left Liverpool on 4th July, 1840, and arrived in Boston a fortnight later. The return voyage was made in a little over

ten days, the best steaming having been 280 miles in a day. They were paddle-wheel boats. They had a line of ports, and were barque rigged. The fare was thirty-three guineas to Boston, or about three pounds a day. The accommodation was described as luxurious; but as the *Britannia* was the boat on which Charles Dickens crossed the Atlantic in 1842 and of which he has placed on record a most depressing account (see page 95), the above description of the accommodation must be accepted with reserve.

Wooden vessels continued to be built for the Cunard Line, until the iron paddle steamer, the *Persia*, was constructed for the company by Robert Napier in 1855. This vessel is described at page 29.

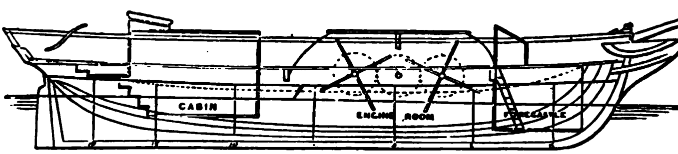


FIG. 12.—The *Comet*. Longitudinal Section.

FIG. 13.—The *British Queen*. 1838.

CHAPTER II.

SHIPBUILDING IN IRON AND STEEL.

TOWARDS the commencement of the last century iron began to be more largely employed than ever previously in engineering structures. Timber suitable for shipbuilding was becoming more and more scarce and expensive, and it became inevitable that, sooner or later, naval architects would turn their attention to wrought-iron.

There were certainly great obstacles to be overcome before such a revolutionary departure in shipbuilding could be undertaken. In those days scientific education was not valued, and was difficult to obtain. Engineering practice was a matter of precedent and tradition, and nothing could possibly be less in accordance with precedent, or more opposed to tradition than that a structure, whose first purport was to float, should be made of a material of far greater specific gravity than water. Even down to the middle of the last century many experienced shipbuilders would have nothing to say to iron, some declaring that to build a vessel of a heavy metal was "contrary to nature."

Even Government departments joined in the opposition. Iron ships had become common before the Post Office authorities sanctioned their use for conveying ocean mails, and it was not till the year 1860 that the Admiralty laid down the first British armoured warship in the new material.

When the prejudice against the use of iron had been overcome it was recognised that this metal possessed great advantages

over timber as a material for construction. In spite of its relatively high specific gravity ships constructed of iron were far lighter than those of corresponding size built of timber. For example, in wooden cargo ships the weight of the hull and fittings varied from 35 to 45 per cent. of the total displacement, while in iron cargo steamers and sailing ships it varied from 25 to 30 per cent. In round numbers it may be stated that the use of iron resulted in a saving of about one-third of the weight of hull for vessels of the same dimensions. This saving, of course, implied a corresponding addition to the carrying and, therefore, the earning power of the vessel. Another great advantage attending the use of iron was the increased structural strength thereby attainable, especially in large ships. With timber it was practically impossible to build steamers 300 feet long. In spite of all devices wooden ships of this size showed dangerous signs of weakness, whereas the *Great Eastern*, built in iron of the length of nearly 700 feet and launched as far back as the year 1858, was, structurally, perfectly satisfactory. Steel vessels exceeding that length have since been constructed.

Richard Trevithick, who proposed and carried out so many novelties in engineering, and who was probably the boldest, most imaginative, and most far-seeing engineer of the early part of the last century, appears to have, in conjunction with a Mr. Dickenson, suggested as a novelty in the year 1809 that ships should be built of iron. Their ideas were far-reaching, for they intended to construct, not only the sides and frames, but also the decks and beams, and the masts, yards, and spars of plate iron. It is not, however, known that the proposal was actually carried out, for the first iron vessel constructed in the nineteenth century of which there exists any record was the *Vulcan*, built in 1818, at Faskine, on the Monkland Canal, eleven miles from Glasgow.

Fig. 14.—The *Britannia*. 1840.

The name of the builder who had the courage to construct this boat, and who thus conferred upon his country far-reaching benefits, of which he himself had probably but little idea, was Thomas Wilson; and it is worthy of notice that his material was so good and his workmanship so sound, that the *Vulcan* was still afloat—not preserved as a historical curiosity, but actually doing hard work in transporting coal from the Forth and Clyde Canal to the river Clyde—as recently as the year 1875, and, for aught that is known to the contrary, may also have been usefully employed for many years subsequently to that date.

The first iron steamer was built three years later, in 1821, at Horsley. She was named the *Aaron Manby*, and was constructed for the joint account of Captain (afterwards Admiral Sir Charles) Napier and Mr. Manby. The parts were put together in London, and she made her first voyage to France under the command of Captain Napier. Another iron vessel was, immediately afterwards, made in this country, and the parts were sent to Charenton, in France, to be put together. This boat was intended for the navigation of the Seine.

In 1824 a good opening was found for the employment of iron steamers in Ireland in the navigation of the River Shannon and its loughs. The first of these boats was built at Horsley. It proved most successful, and the order was given for others. In the year 1829 Mr. William Laird, of Birkenhead, built his first iron vessel, a lighter, of 60 ft. length and 15 ft. beam, ordered by the Irish Inland Company. In 1832 the firm of MacGregor, Laird & Co. built an iron vessel, the *Elburkah*, for the navigation of the Niger. This boat was 70 ft. long, 13 ft. wide, and 6 ft. 6 in. deep. Her bottom plating was a ¼ in. in thickness, her sides ⅛ in., and her weight of hull 15 tons. The *Elburkah* was followed by the *Lady Lansdowne*, built to ply on Lough Derg in Ireland.

Two years afterwards the same firm built a vessel called the *Garry Owen*, which was destined, thanks to an accident, to establish public confidence in the strength of iron ships. She was 125 ft. long by 21 ft. 6 in. beam, and was fitted with two engines, collectively of ninety horse-power. During her first voyage she was driven on shore in a violent gale, as also were many other vessels built of wood. The *Garry Owen* was the only one that escaped without injury, the others having been either totally wrecked or seriously injured. She owed her preservation solely to the strength of her construction. After this event iron gradually came into use as a material for the construction of coasting vessels. Among the best known of these was the once famous steamer *Rainbow*, built in 1837 by Messrs. Laird for the trade between London and the outports. This was the largest iron vessel that had yet been launched. She was 185 ft. long by 25 ft. beam, and of 600 tons. She was fitted with engines of 180 horse-power. About the same time the Birkenhead firm built iron vessels for the Nile and for the exploration of the Euphrates.

The era of iron shipbuilding may fairly be said to have been established when the *Great Britain* was completed at Bristol by Mr. Patterson in 1843, after the plans of Mr. Brunel. This vessel was in every respect a revolution on existing practice; for, not only was there no precedent for constructing such a large ship of iron, but she was also one of the very earliest to be propelled by means of a screw, and was further by far the largest vessel of any description hitherto built for ocean steam navigation. Her leading dimensions were:—Length over all, 322 ft.; length between perpendiculars, 296 ft.; extreme breadth, 51 ft.; depth of hold, 32 ft. 6 in.; draught of water, 16 ft.; and gross tonnage, 3,270 tons. Her engines were of 1,000 horse-power nominal. She was provided with six short masts, five of which were rigged with

fore-and-aft sails. On her first voyage, from Bristol to London, the *Great Britain* encountered very severe weather, and her behaviour amply justified her designer and builder in their choice of material and of propeller. In the year following her launch the *Great Britain* was placed on the American station, and was unfortunately stranded in Dundrum Bay, on the coast of Ireland, and remained on the beach all the winter; but, so strongly was she built that she sustained very little injury. In fact, this mishap, like that to the *Garry Owen*, did much to establish the credit of iron ships. She was employed for considerably over thirty years, for the most

FIG. 15.—The *Great Britain*.

part in the trade between Liverpool and Australia. She was subsequently converted into a sailing ship, and finally broken up at Barrow, having been fifty-seven years in existence. Her structural arrangements are described on page 139, and an account of her machinery is to be found in the "Handbook on Marine Engines and Boilers." The *Great Britain* may be regarded as the forerunner of the iron screw mercantile steamers which eventually regained for this country the supremacy in

the ocean-carrying trade of the world, which was for a considerable time seriously threatened by our American rivals. Fig. 15 is an illustration of this famous vessel as originally rigged.

The iron shipbuilding trade about this time became firmly established on the Thames and Clyde, and it has remained to this day one of the staple industries on the latter river.

In the year 1842 Messrs. Laird applied the new material to the construction of war vessels by building an iron frigate for the Mexican Government. It was named the *Guadaloupe* and was of the following dimensions:—Length, 187 ft.; beam, 30 ft. 1 in.; depth of hold, 16 ft.

The Admiralty for a long time opposed the use of iron in ships of the Royal Navy and in mail steamers under their control. It was assumed, apparently without experiment, that shot would tear large gaps in the sides of iron ships which it would be difficult, if not impossible, to close; whereas, when shot penetrates the sides of wooden ships, the hole partly closes up of itself and is very easy to plug. The earliest experience gained under fire in the use of iron vessels was with the *Nemesis* in the first China war. Captain Hull, who commanded this vessel, stated in evidence before the Committee on Naval Estimates, which sat in 1848, that she was struck by shot fourteen times, that the holes made were clean, and that there were no splinters. Nevertheless, as lately as 1861, the Admiralty were so convinced of the superiority of wood for warship construction that a vote of nearly a million sterling was obtained from Parliament in that year for the purchase of timber. The new material was, however, finally adopted because of the impossibility of constructing the sterns of wooden vessels strong enough to withstand the action of the screw shaft. An account of the remarkable progress in iron shipbuilding afterwards achieved by the Admiralty designers is given in Chapter III.

Fig. 16.—The *Himalaya*. 1853.

This vessel was remarkable for her strength of construction. She was fitted with six transverse watertight bulkheads, which divided the hull into seven watertight compartments, in addition to which there were four caisson compartments. Her longitudinal strength was secured by five keelsons from stem to stern, and in order to provide the greatest strength against collision the bow framing was diagonal. She carried 300 passengers and 1,800 tons of coal. The *Scotia* crossed the Atlantic in eight days twenty-two hours from New York to Liverpool, including the time of detention for landing passengers and mails at Queenstown. In 1871 she was converted into a twin-screw cable ship and was still at work in 1896. In 1862 the Cunard Company built their first iron screw-steamer, the *Russia*, which, though much smaller than the *Scotia*, and with engines of less power, was capable of crossing the Altantic in a rather shorter time. The *Russia* was built by Messrs. J. & G. Thomson of Clydebank. In, or about, the year 1885 she was lengthened and renamed the *Pennland* and ran from Antwerp to New York. So lately as the year 1894 she was still running from Liverpool to New York.

The earliest of the great Transatlantic steamship owners to adopt iron steamers was Mr. Inman, of the Liverpool, New York, and Philadelphia Steamship Company, which was commonly known as the Inman Line. In 1850 he purchased the *City of Glasgow*. This vessel, an iron screw-steamer, built by Messrs. Tod & Macgregor, of Glasgow, was of 1,600 tons, and 300 nominal horse-power. At that time there was but little confidence felt in the screw as a propeller, and the experiment of despatching this vessel across the Atlantic in winter was regarded as very hazardous. The event, however, justified Mr. Inman's expectations, and in the following year his company purchased the *City of Manchester*. The dimensions of this vessel were:—Length on deck, 275 ft.; breadth of

Fig. 17.—The *Persia*. 1856.

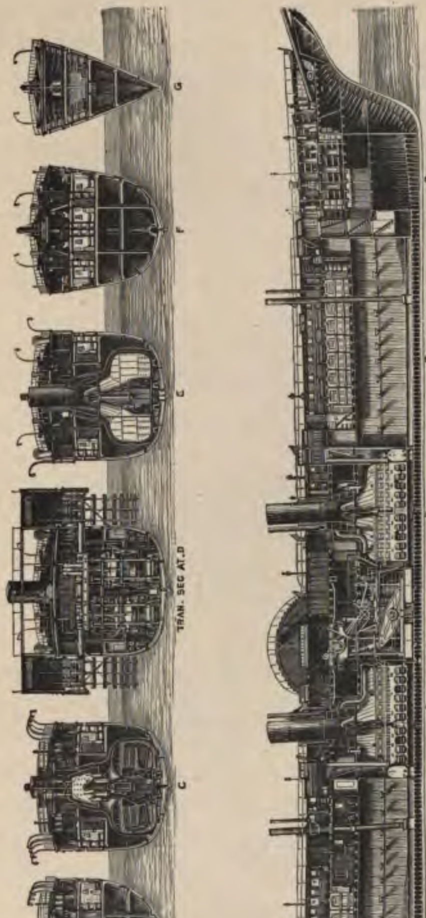


FIG. 18.—Cunard Steamer *Scotia*.

beam, 38 ft.; she registered 2,125 tons; and her engines were of 400 horse-power nominal. She was followed by a series of iron screw-steamers of continuously increasing size, some of which will be referred to hereafter.

In the year 1852 two iron screw-steamers named the *Victoria*, and the *Adelaide*, Fig. 19, were built for the Australian Royal Mail Steam Navigation Company by Mr. Scott Russell. They were designed by Mr. Scott Russell and Mr. I. K. Brunel. They gained the prize of £500 offered by the Colonies for the fastest voyage to Australia. Their dimensions and a full description of their structural arrangements, which were of a remarkable character, are given on page 146. The engines were of the inclined, oscillating type. There were four cylinders of 48 in. diameter and 33 in. stroke, arranged in pairs, similarly to the paddle engines of the *Great Eastern* (*see* " Handbook on Marine Engines and Boilers," page 32). The steam pressure was 15 lbs. per square inch. The screw propeller was 15 ft. in diameter and 22 ft. pitch, and the speed under steam alone was 11 knots.

While the great mail companies were thus engaged in the construction of magnificent iron steamers and vying with each other in producing the fastest, the strongest, and the most comfortable vessels, the merchant shipowners of the country were making steady progress in the development of the screw cargo steamer and, in proportion as the engines were improved in economy, the sphere of the employment of this type of vessel was extended and the use of sailing ships correspondingly restricted. The introduction of the compound engine for marine purposes in the year 1856, in the ships of the Pacific Steam Navigation Company, roughly speaking, reduced the coal consumption to one-half of what it had hitherto been in the most economical engines, and proportionately increased the cargo-carrying capacity, and thus rendered possible great

Fig. 19.—The *Adelaide*. 1852.

economies in the working of steamers. As previously mentioned, this invention gave the final death-blow to the splendid lines of American wooden clippers which had competed so largely for the carrying trade between the Northern States of the American Union and Europe. The opening of the Suez Canal, in 1869, by shortening the route to the East, caused an enormous development in the use of iron screw-steamers for the trade with India, China, and Australasia.

The decade 1850-60 not only witnessed the introduction of iron steamers into the principal passenger lines, but was also remarkable for the construction of the *Great Eastern*, which was the largest vessel that had been built up to that time, and was probably the largest—and certainly the most remarkable—iron structure, for either land or sea. The *Great Eastern* was originally intended by the famous engineer, Mr. I. K. Brunel, to trade between this country and the East. She was designed to make the voyage to Australia without calling anywhere *en route* to coal, a feat which in the then state of steam-engine economy, no other vessel could accomplish. It was supposed that this advantage, coupled with that of the high speed expected from her great length, would secure for her the command of the enormous cargoes which would be necessary to fill her. Mr. Brunel communicated his idea that such a vessel should be constructed for the trade to the East to the famous engineer and shipbuilder, the late Mr. John Scott Russell, F.R.S., and he further persuaded his clients, the directors of the Eastern Steam Navigation Company, of the soundness of his views, for they resolved that the projected vessel should be built for their company, and entrusted the contract for its execution to the firm of John Scott Russell & Co., of Millwall. Mr. Scott Russell and Mr. Brunel

were, between them, entitled to the credit of the design, which, on account of the exceptional size of the ship, presented special difficulties, and involved a total departure from ordinary practice. The details of the construction are of great interest, and are fully described in a subsequent chapter; but, as everything connected with this great engineering achievement is of historic importance, it may not be out of place here to relate, on Mr. Scott Russell's authority, the share which each of those famous men had in her design.* To Mr. Brunel was due, as stated above, the original idea that such a ship should be built. He also suggested that the structure of the tubular bridge over the Menai Straits should be adapted to the vessel, and this was done by making the upper deck and the bottom cellular. Mr. Scott Russell had systematically, in his own previous practice, constructed iron ships with cellular bottoms, but the cells had only five sides, the uppermost side on the inside being uncovered. Over a large portion, however, of the bottom of the *Great Eastern* the cells were completed by the addition of an inner bottom, which added greatly both to the strength and to the safety of the ship. It was also Mr. Brunel's idea that the great ship should be propelled by both paddles and screw. Mr. Scott Russell was responsible for the lines and dimensions, and also for the longitudinal system of framing, with its numerous complete and partial transverse and longitudinal bulkheads. The details of the entire structure, including the adaptation of the box-girder principle to the circumstances of the case, were designed by him; and he also carried the whole design into execution, and further devised and built the paddle engines, which are fully described in the "Handbook on Marine Engines and Boilers."

* *The Times*, April 20th, 1857.

Fig. 20.—The *Great Eastern*. 1858.

The following are some of the principal dimensions and other *data* of the *Great Eastern* :—

Length between perpendiculars	680 feet.
Length on upper deck	692 „
Extreme breadth of hull	83 „
Width over paddle-box	120 „
Depth from upper deck to keel	58 „
Draught of water (laden)	30 „
Weight of iron used in construction	10,000 tons.
Number of plates „ „	30,000
Number of rivets „ „	3,000,000
Tonnage, gross	18,914 tons.
Nominal power of paddle engine	1,000 H.P.
Nominal power of screw engines	1,600 „

Illustrations of this vessel and of details of its structure are shown in Figs. 20, 69, 71 and 71A.

The accommodation for passengers was on an unprecedented scale. There were no less than five saloons on the upper, and as many on the lower deck, the aggregate length of the principal apartments being 400 feet. There was accommodation for 800 first-class, 2,000 second-class, and 1,200 third-class passengers, and the crew numbered 400. The upper deck, which was of a continuous iron-plated and cellular structure, ran flush from stem to stern, and was twenty feet wide on each side of the hatchways; thus two spacious promenades were provided, each over a furlong in length. The capacity for coal and cargo was 18,000 tons.

The attempts to launch this vessel were most disastrous, and cost no less than £120,000, an expense which ruined the company. A description of the method of launching would not be germane to the subject of this handbook, but it may be mentioned that the *Great Eastern* finally floated on the 31st of January, 1858, the first attempt having been made on the preceding 3rd of November. The original company was wound up, and the great ship sold for £160,000 to a new company, and was completed in the year 1859. The new

company very unwisely determined to put her on the American station, for which she was in no way suited. During her preliminary trip the pilot reported that she made a speed of fully 14 knots at two-thirds of full pressure, but the highest rate of speed which she attained on this occasion was 15 knots, and on her first journey across the Atlantic the average speed was nearly 14 knots, the greatest distance run in a day having been 333 nautical miles. The great value of the system adopted in her construction was proved by an accident which occurred during one of her Transatlantic voyages. She ran against a pointed rock, but the voyage was continued without hindrance. It was afterwards found that holes of the combined length of over 100 feet had been torn in her outer bottom; but, thanks to the inner watertight skin, no water was admitted. The *Great Eastern* was never employed on the service for which she was designed, and, in spite of her merits as an engineering work, she proved a disastrous failure commercially. She was, however, usefully employed in 1865 and the following year in laying two of the Atlantic telegraph cables, and subsequently on similar work in other parts of the world. After a long career of inactivity she was sold to break up in the autumn of 1888. (For further particulars of the construction of the *Great Eastern* see pp. 148 to 155.)

About the same period that the *Great Eastern* was being finished for sea, noteworthy improvements were made in some of the coasting passenger iron steamers of the country. By far the most important passenger and mail service on our coasts is that carried on between England and Ireland, *viâ* Kingstown and Holyhead, and we should naturally expect to find on this route some of the best early examples of mail steamers. The City of Dublin Steam Packet Company, which was founded so early as 1823, had for years prior to the epoch in question been distinguished for the speed and

Fig. 21.—The *Leinster*. 1860.

excellence of their mail steamers; but, so great and so important was the traffic that the public demand was ever for faster and larger steamers. A Committee of the House of Commons which was appointed to consider the mail contracts, recommended the construction of vessels capable of running at 20 miles an hour, and displacing about 2,000 tons each. Consequently four new vessels were built for the above-mentioned company in the year 1860. They were named after the four provinces of Ireland, and continued to carry the mails for over thirty years. Three of them, viz., the *Connaught*, *Ulster*, and *Munster*, were built by Messrs. Laird, and the *Leinster* (Fig. 21) was built by Samuda Brothers, of London. They were paddle-wheel boats, the engines of two of them, viz., the *Connaught* and *Leinster*, having been built by Messrs. Ravenhill, Salkeld & Co., while those for the remaining two were constructed by Messrs. James Watt & Co., of Birmingham. A model of one of the sets, built by Messrs. Ravenhill, has been described in detail in the "Handbook on Marine Engines and Boilers," page 30. These four vessels were designed with the greatest care, and constructed with every regard for safety. The three built by Messrs. Laird were of the following dimensions: length 348 ft., breadth 35 ft., depth 20 ft. 3 in., displacement 2,039 tons. They were each provided with nine watertight bulkheads, which divided the vessels into ten compartments. The results were remarkable, and greatly in advance of anything that had hitherto been attained. The *Leinster* on her trial trip developed a mean speed of 20½, and the *Connaught* of 20¾ statute miles an hour. Nothing could be more satisfactory than their performances as sea-boats, a statement which is proved by the great regularity of their passages. During fourteen years the mean time of the passage between Kingstown

and Holyhead was 3 hrs. 56 mins., and there was, on the average, only five minutes difference between the passages in the winter and summer half-years. As originally built these vessels were fitted with hurricane decks forward, and with upper decks about fifty feet long above the engine-rooms. After about twenty-five years' service they were altered, and the accommodation greatly improved by the addition of hurricane decks aft; at the same time forced draught appliances were fitted to the boilers, with the result that the average length of the voyage was reduced and, at the end of twenty-eight years' incessant employment, these vessels were better and faster than when first built. It may here be mentioned, though it is somewhat out of the chronological order, that, in the year 1885, this fleet was supplemented by the paddle-steamer *Ireland* (Fig. 22), built by Messrs. Laird. This vessel was, in respect of size, accommodation, and speed, an improvement on her predecessors. The following were the principal dimensions of the *Ireland* :—

Length over all	380 feet.
Length between perpendiculars	360 ,,
Breadth	38 ,,
Depth of hold	19 ft. 3 in.

The engines, which were of the non-compound oscillating type, had cylinders of 102 in. diameter and 102 in. stroke. The boiler pressure was 30 lb. per square inch. The indicated horse-power under natural draught amounted to 5,000, and under forced draught to 6,000. The speed on trial was 20·25 knots, equal to 23·3 statute miles. The passage from Holyhead to Kingstown was easily effected in three hours.

Between the years 1860 and 1870, the use of screw iron steamers became general, not only in the European coasting trades, but on Transatlantic waters, and also on many of the most distant trade routes, such as those to China and

Fig. 22.—The *Ireland*. 1885.

Australia. This result was mainly due to the improvements in the marine engine, described in the "Handbook on Marine Engines and Boilers." These improvements, which consisted chiefly in the use of higher pressures, surface condensation, and compounding of the cylinders, resulted, in round numbers, in a saving of half of the fuel which had hitherto been consumed in the best types of marine engines. A reduction of fuel from four pounds to two pounds per indicated horse-power per hour rendered profitable the employment of screw-steamers in many trade routes in which sailing vessels had formerly held their own.

Beyond the improvements in the engines and the gradually increasing size and power of steamers, there is nothing peculiarly novel to chronicle during this period, as far as the mercantile marine is concerned. The structural arrangements continued to be what they had been from the beginning, and the longitudinal system introduced by Mr. Scott Russell, and exemplified by the *Great Eastern* and many other ships, though adopted by the Admiralty and modified to suit their requirements, had not been followed up in the mercantile marine. In the year 1876, however, the gradually increasing use of water ballast caused the technical advisers of Lloyd's Registry of British and Foreign Shipping to turn their attention to a system of construction in which the water-ballast tanks formed an integral portion of the ship's structure, instead of being, as hitherto, a heavy addition to the weight of hull. The first result was the building, by Messrs. Austin & Hunter, at Sunderland, of a small iron vessel, called the *Fenton*, the bottom of which was a combination of the longitudinal and transverse systems of framing, similar in principle to the plan which had been for many years in use in the Royal Navy. The details of this system are described and illustrated in the chapter on the structure of ships

(see p. 165). The example thus set was followed immediately by Messrs. Denny Bros., of Dumbarton, and subsequently by many others of the large shipbuilders, and has since become general in steamers of the first class. Though originally adopted with a view to improving the arrangements for carrying water ballast, the projectors of this scheme, of course, took account of the increased longitudinal strength obtained with their designs.

Steel for Shipbuilding.

The next great departure in shipbuilding was the substitution of mild steel for iron, as the material of construction. Steel had been used at intervals previous to the year 1873 in shipbuilding, but only for vessels of very special type. It was not possible to use it more freely, because there was no supply of trustworthy material at a moderate price, till the late Sir William Siemens perfected the open-hearth process of manufacturing mild steel. To the French belongs the credit of having been the first to recognise the advantages of mild steel for shipbuilding purposes, they having introduced it into portions of the structure of warships in the early part of the year 1873. Mr., afterwards Sir, Nathaniel Barnaby, Director of Naval Construction at the Admiralty, challenged the steel makers of the United Kingdom to produce a material equal to that manufactured in France. Mr. W. H. Riley, then of Landore, took up the challenge and succeeded in producing steel having the required qualities, and to him therefore is due the credit of having inaugurated the epoch of mild steel shipbuilding in Great Britain. The Admiralty were enabled in the year 1873 to order the construction of two despatch vessels, the *Iris* and *Mercury*, which were to be wholly of the new material made at Landore. About the year 1877 considerable attention was given to it by mercantile

shipbuilders, and particulars were received at Lloyd's Registry of 5,000 tons of sailing ships and 18,000 tons of steamers proposed to be built of mild steel. In the year following, 4,500 tons of steel shipping were actually classed by that society, and from that time onwards the use of this material rapidly extended, and at the present moment practically all steamers and large sailing ships are built of it.

The advantages of mild steel over iron are that its ultimate tensile strength is from twenty-five to thirty per cent. greater than that of the best iron ship-plates; while at the same time it is very ductile and malleable, homogeneous in substance, and uniform in quality. The strength, moreover, is the same in every direction; whereas, in the case of iron plates formerly used for shipbuilding, it is well known that the strength was from fifteen to twenty per cent. greater when tested in the direction of the length of the plate than it was when taken breadthwise. The ratio of the elastic limit to the ultimate breaking strain in the case of mild steel is greater than the corresponding ratio of iron; hence the working loads, which steel can safely bear, exceed the safe loads of iron, at least, in proportion as the tensile strength of the new exceeds that of the older material. This is a very important feature, regard being had to the fact that mild steel is also much more ductile than iron. In consequence of the superior strength of steel, the registration societies at first found it possible to reduce by twenty per cent. the scantlings of vessels built of this material. The total saving in weight did not, however, amount to as much as twenty per cent., because the hull includes forgings and fittings, and also woodwork, the weights of which remain unaffected. The real saving in the earlier vessels classed at Lloyd's was from thirteen to fifteen per cent. of the weight of a similar vessel constructed in iron. Extended

experience, however, proved that it was not desirable to reduce all the scantlings to the extent at first thought possible, and in the types of large steel cargo steamers in vogue about 15 years ago the saving in weight was considerably less than that given above. The saving in weight of hull on given dimensions, of course, means increased carrying powers of cargo and coals, or the realisation of some other advantage in special types of steamers, such, for instance, as the use of more powerful machinery in passenger ships. The combination of steel hulls with the economic types of triple-expansion high-pressure engines means such an increase in the cargo carrying and, consequently, earning powers of steamers, that the older types of vessels compete with them at great disadvantage.

When mild steel was first introduced various difficulties had to be overcome. It was found that many of the earlier vessels constructed of this material suffered from the effects of corrosion, the bottom plates pitting in some cases in the most remarkable manner. It was discovered, after some trouble had occurred, that this corrosion was due to the presence on the plates of small pieces of mill scale, or magnetic oxide of iron, which, like most of the oxides of metals, is extremely electro-negative in character and, consequently, forms with the metal of the plates in the presence of sea water an active galvanic couple. This accounted for the deep local pitting which took place. The difficulty has now been to a great extent got over by the process of pickling the plates in a bath of dilute hydrochloric acid, which removes the scale. The plate is then freed from the acid of the bath by washing in an alkali. Similar results may be obtained by allowing the oxide to scale off by weathering, or by brushing after the material has been worked.

en after the above-mentioned precautions have been

taken, it appears that mild steel plates are more liable to suffer from corrosion than the comparatively impure iron formerly in use, but the difficulty can always be met by having vessels made of the new material scraped and properly painted at regular intervals.

In the early days of steel shipbuilding the manipulation and working of the material caused some difficulties. The operations of punching, bending, and riveting sometimes caused plates to crack, but in the great majority of cases it was found either, that the plates were not of uniform quality throughout, or else that they were worked at a temperature between 400° and 600°, commonly called a "blue heat." It has been found in practice that, between the above limits of temperature, the ductility of mild steel is much reduced, and the metal is consequently in a very dangerous state for working. These difficulties have, however, gradually been overcome. The want of uniformity in the qualities of different parts of the same plate has been removed, thanks to the knowledge gained in the testing to which all plates used in shipbuilding are subjected at the producing works. The difficulties in working have been got over in proportion as the men gained experience in the manipulation of a novel material, and shipbuilders now report that their workmen experience much less trouble in constructing a vessel of mild steel than of iron.

The value of mild steel in resisting many of the accidental strains to which the parts of ships are occasionally subjected has been proved over and over again by the way in which the material has bulged and bent, instead of breaking, when exposed to the shocks of collision and grounding.

From the shipowners' point of view, one of the most important questions was to ascertain whether the increased carrying power could be obtained at a price which would permit of a

remunerative return on the extra capital invested. This was altogether a question of the relative prices of iron and steel plates, angle irons, forgings, etc., and of the rates of freight obtainable at any given time. So far back as the year 1881, when steel was, relatively, expensive material as compared with iron, the late Mr. W. Denny, of Dumbarton, read an interesting paper on this subject before the Iron and Steel Institute, in which he worked out the comparative results of a spar-decked steamer of about 4,000 tons gross. This vessel was a passenger steamer engaged in the Eastern trade, and capable of carrying cargo. The following are the principal figures :—

Weight of iron in the iron steamer	= 2,123 tons,	costing £14,501	= £6·25 per ton.
Weight of steel and iron in the steel steamer ..	= 1,847 „	„ £18,075	= £8·9 „
Difference representing increased dead-weight capacity of steel steamer ..	275 „	„ £3,574	= £13 „

This vessel was capable of making seven single voyages per annum between London and Calcutta. The freight per ton of dead-weight capacity was estimated at £1 per voyage, or £14 in two years. The cost of marine insurance for the same period at 7 per cent. would come to 36*s*., leaving net receipts of £12 4*s*. These figures proved that the extra cost of the steel steamer, under the above conditions, would be recouped in a little more than two years. It is, therefore, not surprising that the popularity of the new material was great from the outset.

In the year 1885, Professor Biles read a paper before the Iron and Steel Institute in which he showed that, at the prices then ruling for steel and iron, viz. £6 9*s*. 0*d*. and £4 19*s*. 3*d*. respectively, and taking into account the saving in weight and other advantages belonging to the new material, a *ship* could be built on the Clyde, to class at Lloyd's, at least

as cheaply in steel as in iron. At the present time (1906), the steel-built ship costs much less than one constructed of iron. The following figures, taken from the returns of "Lloyd's Register of British and Foreign Shipping," show the extent to which each material was used in the years 1881, 1889, 1899 and 1905, in the construction of ships registered in the United Kingdom :—

Year.	IRON. Registered Tonnage.	STEEL. Registered Tonnage.
1881	71,533	659,153
1889	75,003	1,104,196
1899	15,562	1,347,181
1905	363	1,622,805

In the Royal Navy the use of steel became universal before it was adopted at all in the mercantile marine. In fact, when the qualities of the material were established its advantages for the construction of warships were never for a moment in doubt.

Its introduction in the Royal dockyards was also facilitated by the absence of the complications due to commercial considerations; for, in the Navy, steel had not to compete with the relatively cheap iron used in the construction of merchant ships but with the very superior and costly qualities of iron which had always been used in the Admiralty service. This remark, however, does not apply to the case of the *Iris* and *Mercury*; the steel for these ships cost £19 per ton, which was much more than the price of Admiralty iron ship plates at that time.

About the time that the French Ministry of Marine were making their first experiments in the use of steel for shipbuilding, another improvement was introduced, which was destined to be of the greatest service to both the mercantile

marine and the Royal Navy. This was the application of three stage-compounding, or triple-expansion, to the engines of the *Propontis*, by Mr. A. C. Kirk, in the year 1874. A full account of the introduction of this invention is given in the "Handbook on Marine Engines and Boilers," page 88, and is now referred to on account of its influence on the commercial efficiency of the ship. The advantage gained to the merchant shipowner is the saving in the fuel consumed, which means, not merely a reduction of no small importance in the coal bill, but also an increase in the freight-earning capacity of the ship. The saving in fuel over that consumed in the ordinary compound engine varies, according to the circumstances of the case, from 20 to as much as 33 per cent. The effect of this great improvement in increasing the carrying capacity of steamers may be made apparent by an example given by the then chief engineer surveyor of Lloyd's Registry, in a paper read before the Institution of Naval Architects in the year 1886.*

The comparison made was between two steamers engaged on the India trade; the first had a gross tonnage of about 2,200 tons, with ordinary compound engines working at a steam pressure of 90 lbs. per square inch. This vessel steamed 10 knots, with a daily coal consumption of 20 tons, and was capable of carrying 3,000 tons of cargo, including coal. The second vessel was of 2,800 tons gross, and was fitted with triple-expansion engines working with an initial pressure of 150 lbs. of steam. The speed and the coal consumption were exactly the same in both instances in spite of the difference in size, but the cargo carried in the latter vessel was 4,200 tons, or 1,200 tons more than in the former.

* "On the Progress and Development of Marine Engineering," by Mr. W. Parker. *Transactions of the Institution of Naval Architects*, vol. xxviii. p. 129.

Many questions connected with the engines, in addition to that of fuel economy, are of great importance to the shipowner. Before triple-expansion engines became universally popular it was necessary to prove :—

1st. That they did not occupy a greater space in the ship for a given power than the ordinary compound engines.

2nd. That the weight for a given indicated power was not greater.

3rd. That the wear and tear of the machinery was not greater.

Fortunately, the proof in each instance was forthcoming. The best arrangement of the triple-expansion engine is with all three cylinders in line ; but, in spite of the presence of an extra cylinder, it has been found easy in practice to find room for engines of this type in the fore and aft space that would be occupied by an ordinary compound engine. The weights of the triple-expansion engine per indicated horse-power, including the weights of boilers and water, is actually rather less than the corresponding figures for ordinary compounds. In the case of the more modern engine, the total weight of machinery and water per indicated horse-power varies between 450 and 470 lbs., while in the older practice the weight was seldom less than 480 lbs., and often exceeded 500 lbs. Lastly, the wear and tear of the triple-expansion engines is not greater than that of the ordinary compound, and in many cases has even worked out less.

It was at first feared that the high-pressure boilers of the triple-expansion type would give much more trouble, both in the manufacture and in working at sea, than those of the older type. Fortunately, however, the introduction of mild steel, which proved such an advantage to the shipbuilder, turned out to be equally useful to the boiler-maker. Also the mechanical appliances used in the manufacture of boilers

have been so much improved that there is no greater difficulty to-day in turning out steam-generators, working at the pressure of 170 lbs. to 220 lbs., than there was formerly in producing boilers suitable for working at 90 lbs. At first some difficulty was experienced at sea, and a few failures of furnace crowns occurred; but when the peculiarities due to the use of very high pressure were better understood, the difficulties disappeared one by one. We may, therefore, pronounce the triple-expansion engine as one of the greatest successes in the whole history of steam navigation. More recently four stage-compounding, or quadruple-expansion, has been introduced and many important ships are now fitted with engines of that type.

CHAPTER III.

INFLUENCE OF THE ADMIRALTY ON SHIPBUILDING IN IRON AND STEEL.

HITHERTO reference has been chiefly made to merchant ships. The structure of warships belongs, however, essentially to the domain of civil manufacturing industry, and has, moreover, exercised from time to time a powerful influence upon the structural features of purely mercantile vessels; consequently, an historical sketch of iron and steel shipping which ignored what has been achieved with war vessels would be wanting in completeness.

It has been previously mentioned that so early as the year 1837 a frigate was built of iron by Messrs. Laird for the Mexican Government, and that some favourable experience with an iron vessel called the *Nemesis* was gained in the China War in the year 1840, but that, nevertheless, there was great prejudice at the Admiralty against the use of this material.

The experience gained by the English and allied fleets in the Crimean war proved that unprotected wooden warships were totally incapable of withstanding the effects of shell fire. During the progress of the war, armour-clad batteries were, on the suggestion of the Emperor of the French, constructed both in this country and in France, and three of the French batteries were actually used in the bombardment of Kinburn in 1855.

In 1856 the two paddle-wheel iron gunboats named the *Bann* and the *Brune* were designed and constructed by Mr. John

Scott Russell for the Admiralty. These boats were built on the longitudinal system, with fore and aft bulkheads dividing the side bunkers from the engine and boiler rooms, and with iron decks uniting the tops of these bulkheads with the sides of the ship. They were each 140 ft. long on load water line ; 20 ft. beam, 8 ft. 6 in. deep, and only 4 ft. draught.

The results obtained with the floating batteries were considered sufficiently satisfactory to warrant an attempt at introducing sea-going armoured vessels in the French Navy, and in the year 1858 the first sea-going ironclad frigate, the *Gloire*, was commenced at Toulon, from the designs of the famous French naval architect, the late Monsieur Dupuy de Lome. This vessel was constructed of wood and was merely protected by iron armour, and cannot therefore be considered as having played a part in the history of iron ships.

The English Admiralty was compelled by the action of the French Government to introduce armour into our Navy. The combination of a timber structure with iron protection was, at the outset, looked upon in this country with grave distrust, and our Admiralty determined that the first British sea-going ironclad should be also an iron ship. The *Warrior* was accordingly laid down in 1859, and was followed immediately by the *Black Prince* and the *Defence* and *Resistance*. The wisdom of the selection of the material of construction made by the Admiralty is proved by the fact that, while the *Gloire* and her immediate successors have long since ceased to exist, the *Black Prince*, though belonging to an antiquated type, was still structurally sound, after a lapse of over forty-five years.

The *Warrior* and *Black Prince* were designed at the Admiralty in agreement with the views of the late Mr. John Scott Russell. Their principal dimensions were—Length 380 ft., breadth 58 ft. 4 in., displacement 9,210 tons. In the design of

these ships, high speed and steadiness of platform were aimed at. The broadside battery was protected for a length of 212 feet by a belt of armour 22 ft. deep and 4½ in. thick, on a backing of 18 in. of teak. The fine ends of the *Warrior*, which were unprotected, were subdivided into numerous compartments by transverse, longitudinal, and horizontal watertight partitions. This vessel carried originally fifty-two of the heaviest guns then used afloat, viz., 68-pounder smooth bores, and her armour was sufficient in area and thickness to completely protect her vital parts against any projectiles that could at that time be brought to bear against her at sea at a range of 200 yards. The speed attained was over 14 knots, or about 1½ knots greater than that of the best frigates and line-of-battle ships of that time.

It is evident that, by reason of her powers of offence and defence, as well as of size, speed, and material this vessel was a complete innovation upon existing types, and her construction may be regarded as an epoch-making event in the history of iron shipping. Her mechanical structure, which is the feature of special importance to readers of this handbook, was as remarkable as the rest of the design. It is described in detail in Chapter VII., p. 157; but, in the meantime, it may be mentioned that it consisted of a combination of the system of longitudinal framing and complete and partial transverse bulkheads adopted in the *Great Eastern* and other vessels, with the ordinary transverse framing at that time and for long afterwards made use of in the construction of the majority of merchant ships. There were added special structural features intended to meet the requirements of the ship as a fighting machine. One feature of particular interest was the introduction on each side of the ship of a longitudinal vertical bulkhead at a distance of about three feet from the inside of the transverse frames, and extending from the main deck

down to the third longitudinal girder in the bottom. See the half cross section of the *Warrior* given in Fig. 73 on page 158. The compartment formed by each of these so-called "wing-passage" bulkheads is watertight, and is further subdivided into two parts horizontally by the stringer plates of the lower deck, and into numerous other divisions by the complete and partial transverse bulkheads. These longitudinal bulkheads conferred great additional strength on the structure of the ship and, thanks to the numerous watertight compartments which they rendered possible, they added greatly to the chances of safety in case the ship should be penetrated below the water-line. The *Warrior* was only provided with a very partial watertight double bottom, under the engine and boiler-rooms, and extending from the keelson to the first longitudinal frame on either side. In the *Northumberland*, which was built shortly after the *Warrior*, the double bottom was extended up to the foot of the "wing-passage" bulkheads.

Limits of space do not permit of a detailed description of the numerous changes of type in the ironclad iron vessels of the Navy which followed the building of the *Warrior*. Nor is such a description necessary for our purpose, because the great majority of changes were made to secure special advantages in the fighting features of these ships, and were rendered necessary by the desire to utilise the ever-increasing power of modern ordnance on the one hand, and to protect the vessels from its effects on the other; other considerations, such as the desire to secure greater handiness in manœuvring, the wish to limit the cost of the individual ship, the necessity of changing from broadside and central batteries to turrets and barbettes, exercised profound influence upon the development of the type of battleships from time to time.

The next important step in advance in the structural arrangements of the iron ships of the Navy was made in H.M.

Ships *Bellerophon* and *Hercules*, designed by Sir Edward Reed (see Fig. 74, p. 160). The principal improvements consisted in the use of much deeper longitudinal frames, which rendered possible the provision of a complete double bottom, everywhere easily accessible. These deep longitudinals, with complete inner bottom, added enormously to the strength and safety of the ship, and have since become general in all the iron and steel warships of the Navy. Their great value has been occasionally proved when British war vessels have accidentally taken the ground, or been run upon rocks. We may quote as instances the accidents which happened to H.M. Ships *Iron Duke*, *Agincourt*, and *Victoria*.

The *Iron Duke* took the ground twice on the China Station, the second time on a rocky bottom, with the result that her outer bottom was broken through and bent for a considerable length, but the inner bottom remained intact, and the vessel was got off and safely brought to port.

The *Agincourt* ran on the Pearl Rock, near Gibraltar. This ship, like the *Warrior*, was only provided with an inner skin over a small portion of her bottom, but fortunately she struck on this particular portion and was saved.

The *Victoria*, built of mild steel, ran on to a shelving shoal with jagged rocks at the speed of nine knots. As the ship weighed fully 11,000 tons, the energy of the collision was some 40,000 ft. tons. About 180 ft. of her length rested on the shoal, and the outer bottom for the first 60 ft. was driven up, and seriously bulged and broken in a few places. So great was the force of the blow that the solid steel stem was broken. Nevertheless, when sufficiently lightened, she was floated off and brought in safety to Malta. This accident was a most convincing proof of the strength of the structural arrangements in the vessels of the Royal Navy, and also of the value of mild steel for shipbuilding.

The depth of water forward, when the vessel struck, was from seven to eight feet less than the draught when afloat. There was a very large excess of weight over buoyancy, a condition of things which brought severe stresses to bear on the general structure of the hull over and above those allowed for in the design. The heavy vessel remained in this position for six days, but her structure generally was found to be absolutely uninjured beyond the local damage caused by impact on the rocky bottom. Even the effects of the impact were minimised by the excellent quality of the mild steel used in the construction. The plates, angles and fastenings are reported to have "bent and doubled under pressure, but fractured in very few instances, and then only to slight extent. . . . Many of the plates removed for repair were so little injured that they have been replaced after having been re-rolled."*

In addition to these instances of the value of the double bottom, the case of the cruiser *Apollo* may be mentioned. This vessel ran on the Skelligs and ripped up her outer skin for a considerable distance, but was brought safely to Chatham for repairs.

Another advantage conferred by the use of a double bottom is that water can easily be admitted into any of the water-tight compartments into which the space between the two skins is divided, and can thus serve as ballast and be used in regulating the trim of the vessel.

There were other features of great interest in the structural arrangements of the double bottoms of the *Bellerophon* and *Hercules* and of the warships which succeeded them. They were designed with the objects of securing strength and water-

* *Transactions of the Institution of Naval Architects,* vol. xxxiii., p. 172. Paper by Sir William White, K.C.B., then Director of Naval Construction, and Assistant-Controller of the Navy.

tight subdivision with economy in the weight of material employed. They are described in detail on p. 161.

The system of framing and of structure of double bottom as practised in the Royal Navy exercised, in course of time, a profound influence on the structural features of mercantile ships. (See the account of the design of the *Fenton*, p. 165.)

The question of watertight subdivisions has been incidentally referred to above. The possibility of dividing up the hulls of ships into separate compartments is one of the great advantages conferred by the use of iron and steel as the material of construction. Subdivision, if properly carried out, is an element not only of structural strength, but of safety. In warships it is indispensable, in order to preserve their powers of flotation when the hulls are penetrated by projectiles. In the earlier ironclads the opportunities for efficient subdivision were limited by the absence of a complete double bottom, and by the fact that there was only one propeller, with its corresponding single main engine, which effectually prevented the use of a longitudinal middle-line bulkhead. With the introduction of mastless ironclads, the use of twin-screws, each driven by a separate engine, became a necessity, and as a collateral advantage permitted the introduction of the middle-line bulkhead. As an illustration of the degree to which watertight subdivision has been developed in the Navy, it may here be mentioned that, whereas the *Warrior* had 35 watertight compartments in her hull and 57 in her partial double bottom and wings, or 92 in all, the *Inflexible*, launched in 1876, was provided with 89 in the hold space and 46 in the double bottom and wings, or 135 in all; and the *Royal Sovereign*, launched in 1891, has 100 in the hold space and 55 in the double bottom and wings, making a total of 155, while the *King Edward the VIIth*, launched in 1903, has in all 204 compartments.

The great mail steamers, and also many cargo steamers, have in recent years under Admiralty influence been much more efficiently subdivided than was formerly the case, while all large mail steamers have been fitted with twin screws. The improvement was largely due to the fact that, about the year 1875, the Admiralty was anxious to form a list of vessels which should be available for purposes of the State, such as the transport of troops and material of war. It was necessary that such vessels should comply with certain conditions and it was laid down that every ship which was placed on the list must be so subdivided that, if any one of her compartments were laid open to the sea in smooth water, the loss of buoyancy thereby occasioned would not endanger her safety. It was found at that time that in the whole British mercantile marine, only some thirty vessels were in existence which complied with this requirement. The attention of shipbuilders was brought to bear on this point by the Admiralty, with the result that in the year 1883 about 300 vessels fulfilled the condition. Some of these were so well subdivided that, if even two compartments were open to the sea, the vessel would still retain sufficient floating power.

In one very important respect Admiralty influence has not yet made itself felt in the mercantile marine of this country. The hull structure of warships is generally much lighter than that of merchant steamers. In view of the fact that extended experience proves that naval vessels show no signs of structural weakness it may be anticipated that, before long, the Admiralty example will be followed by shipowners and by others who are responsible for the structural weights of British mercantile vessels, more especially so, because in some foreign countries the experience of warship constructors has been assimilated with conspicuous success in the construction of ocean-going mail steamers.

CHAPTER IV.

EXAMPLES OF MODERN PASSENGER STEAMERS.

AN account has already been given of several of the prominent steamers that were constructed in the earlier days of ocean steam navigation, and reference will now be made to some of the most important of the more recent vessels.

As it would be quite impossible, within the necessarily restricted limits of this handbook, to notice in detail more than a small proportion of the interesting and remarkable vessels that have been built since the introduction of steel and iron as materials for shipbuilding, attention will be concentrated mainly on the Transatlantic service, which, possibly in consequence of the rivalry and severe competition that exists between the different lines, is, to the general public, the most interesting that exists.

About the year 1871 a new era may be said to have been inaugurated by the entry of the White Star Line into serious competition for Transatlantic passenger service. Although this is not a record of shipping companies, but of steamships, a few words may be said about the origin of a line which has so profoundly influenced ocean travel throughout the world. The *Oceanic* (first of the name) and the five other vessels, the *Celtic* and the *Baltic* (first of the name), the *Republic*, the *Atlantic* and the *Adriatic*, were built to inaugurate this new rivalry on the North Atlantic route. The White Star Line was originally founded as a line of sailing clippers by the late Mr. T. H. Ismay. Having had considerable experience in the

shipping business, he saw that the engineering difficulties of the early days of steam navigation had been overcome, but that much remained to be desired in regard to passenger accommodation. At that date, many of the early traditions that had come down from the old sailing days still remained, and were considered sacred by the steamship owners of the day. Mr. Ismay determined to put his ideas into practice and was fortunate in finding, in the late Sir Edward Harland, a ship-builder of experience who cordially entered into his schemes.

The new White Star boats differed widely from the general ocean liners of their day. The first *Oceanic* had four masts, three of which carried yards. An upper deck of iron was

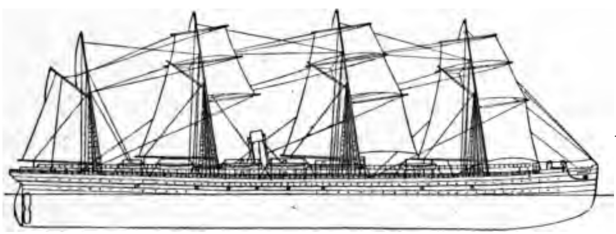


Fig. 23.—The first *Oceanic*, 1871.

added, and iron railings were substituted for bulwarks. These were found to be a great advantage, as the vessel freed herself from water immediately; whereas, under the old system, it was held on deck until it ran off through the scuppers.

The first *Oceanic*, Fig. 23, was 420 ft. long between perpendiculars (432 ft. over all), only 41 ft. wide, and 31 ft. deep. These proportions were found fault with at the time. The success of the design was, however, quickly proved, and in spite of the much criticised small ratio of beam to length, the public freely patronised the new ships. One of the innovations was the placing of the main saloon in the middle length of the ship. As a relic of the olden days—probably handed

down from remote classical times—when the position of importance was near the rudder, or "steer-board"—the place of honour was at the after end of the ship. It is at the ends, however, that the motion due to the waves is greatest, and in screw steamers there also the jar and vibration produced by the propellers is most felt. Passengers, therefore, prefer to be in the middle of the vessel and, as it was one of Mr. Ismay's cardinal principles to do as much as he possibly could for the passengers, it was in the middle of the ship and forward of the machinery that he placed his main saloon.

The engines of the *Oceanic* were made by Maudslay, Sons & Field—a name that is now simply historic—at their once celebrated Lambeth shops, where so many of the great marine engines had been constructed from the earliest days of steam navigation. Formerly shipbuilding and engineering were distinct trades, and Messrs. Harland & Wolff had not then established their extensive engine works at Queen's Island, Belfast. The indicated horse-power of the engines of the first *Oceanic* was about 3,000, and the excellence of the model was shown by the vessel making about 14¾ knots. This was a quarter of a knot more than the previous "fastest on record" made by the Inman Liner *City of Brussels*, a vessel of the same power but of over 300 tons less displacement. At that time the paddle-wheel steamer *Scotia*, referred to on page 29, was the fastest Cunard boat. She was about 1,500 tons greater displacement than the first *Oceanic* and of 1,000 more horse-power. In spite of the greater size and higher ratio of power to displacement of the paddle-wheel vessel, she was a knot and a half slower than the White Star boat.

The *Oceanic* did not, however, long retain her supremacy in speed, having been surpassed three years later by the *Britannic* of the same line. This vessel and her sister ship the *Germanic*

were each 455 ft. long between perpendiculars (468 ft. over all), 45 ft. wide, and 33 ft. 9 in. deep; they were completed respectively in 1874 and 1875 at the Belfast yard, and were engined by Maudslay. They were also fully rigged ships like the *Oceanic*; had a displacement of 9,600 tons; and reached a speed of about 16 knots. The *Britannic*, which came out first, thus stood at the head of the competition for speed; but in the following year (1875) the Inman line, with the *City of Berlin*, also obtained a speed of about 16 knots. This vessel was of much larger size than those previously mentioned, and was the first Atlantic liner to exceed 10,000 tons displacement, and to pass the limit of 500 ft. in length; for she was 520 ft. long over all and 489 ft. between perpendiculars. Her beam was 44 ft.; about a foot narrower than the shorter White Star vessel. Her horse-power was 5,200.

The *Britannic* and the *City of Berlin* did not long maintain their position. They were challenged by three famous vessels named the *Arizona*, the *Alaska* and the *Oregon*. These steamers were built for the Guion Line by the Fairfield Shipbuilding Company on the Clyde. The *Arizona* was brought out in 1879 and was 450 ft. long between perpendiculars (473 ft. over all), and not quite 10,000 tons displacement. Her indicated horse-power was 6,300 and her speed 16¼ knots. Great interest and excitement were caused by these new rivals to the older lines. Two years later the Cunard Company with the *Servia* brought forward a larger and more powerful ship and obtained another quarter of a knot. The length of this vessel was 515 ft. between perpendiculars (544 ft. over all), and her displacement 12,300 tons; her engines indicated 10,000 horse-power and her speed was 16½ knots.

The second of the Guion Line ships mentioned, the

Alaska, which came out in 1881, was a longer and more powerful vessel than the *Arizona,* and made about $17\frac{3}{4}$ knots. She was eclipsed by her ill-fated fellow ship, the *Oregon.* This remarkable vessel was of the same length as the *Alaska,* but about 4 ft. wider, and had 2,000 more horse-power—namely, 13,000 indicated, and attained the speed of 19 knots.

The *Arizona* and the *Oregon* were both notable through the mishaps they met with. The former ran end on into an iceberg one night in mid-Atlantic. Her bow was crushed completely in; but, fortunately, the collision bulkhead was uninjured and withstood the stress imposed upon it. She was navigated to port, and became a standing proof of the sound work put into hull structure by her builders. The *Oregon* was less fortunate. She had been purchased by the Cunard Company and was run into by a mysterious sailing vessel off the American coast. She sank in a short time, but, fortunately, there was time to save the whole of the passengers and the mails.

In 1881 the Inman Line made a determined attempt with the *City of Rome* to obtain the first position once more. This vessel was the first amongst those built, after the *Great Eastern,* to reach the length of 600 ft., that being her measurement over all, while between perpendiculars she was 560 ft. The *Great Eastern* was 692 ft. long over all, and 680 ft. between perpendiculars. The greater ratio of over all to water line length of the Inman boats is to be attributed to the fact that this line adhered to the graceful overhanging, so called ogee, or schooner bow; whilst most of the newer ships had, like the *Great Eastern,* a vertical stem. The *City of Rome,* which was built at Barrow, was 13,500 tons displacement, and 11,500 indicated horse-power. She was credited with $17\frac{1}{2}$ knots speed, but cannot be pronounced to have been a successful vessel.

The steamers hitherto described were either paddle-wheel or single-screw ships. The increasing size of vessels, and the greater power needed to drive them at the speeds demanded by passengers, rendered it more and more difficult to construct engines of the size required, and to transmit the power to the propeller through one line of shafting. Twin-screw vessels, chiefly of smaller classes, had frequently been built; but they were, with some reason, supposed not to be so efficient as single-screw ships. The example set by war-ship designers, and the more scientific methods of investigation that had come into play, put the twin-screw system in a more favourable light. Its greater safety was an important advantage, which was proved by the numerous accidents that occurred owing to the failure of propeller shafting.

Prompted by these considerations, the Inman & International Company, which had acquired the old Inman interests, determined to build two twin-screw vessels of large size and power—the *City of New York*, now called the *New York*, and the sister ship the *City of Paris*, now called the *Paris*. It should here be mentioned that twin-screws are at the present time universal in important passenger liners. Their introduction is therefore an epoch-making event in the history of Trans-atlantic steamships, and the two important vessels above named may be taken as prototypes of modern ocean passenger vessels. They were launched from the yard of Messrs. J. & G. Thomson, Clydebank, in the Spring of 1888. Although these vessels have now been surpassed both in size and speed, they contained so many new features at the date at which they were built that a somewhat extended description may usefully be here given.

The genesis of these ships is remarkable. In the year 1885 the National S.S. Company ordered from Messrs. J. & G. Thomson a steamer for the Atlantic service called the

America, which created a great sensation in her day. The *America* was developed from a design prepared by Mr. (now Professor) J. H. Biles—then in the employ of Messrs. Thomson—for a steamer called the *Stirling Castle*, which was afterwards built at Messrs. John Elder & Co.'s works at Fairfield for Mr. Thos. Skinner. It should be mentioned that the form of both ships was a development of that of H.M.S. *Iris*, but adapted in the case of the *America* for Transatlantic work. Her forefoot was kept much squarer than that of the *Iris* both longitudinally and transversely. Old experienced sailors said that she would pitch so badly that she would not be able to cross the Atlantic in winter, but their fears proved groundless. She was a great success, both in form and speed, for she attained the speed of the fastest vessels of her time for about 25 per cent. less horse-power than her rivals. The *America* was a single-screw prototype of the *Paris*. Though the form of the latter is quite as good as that of the *America* her performance was not at first so good, as her twin-screws and their supports were not so efficient as single screws. She has, however, since been altered, a bossed out stern having been substituted for the original A bracket supports of the propeller shafts. Her efficiency has consequently been greatly improved, for she now attains a speed of 19 knots on 15,000 I.H.P., whereas formerly she required 17,000 I.H.P. to attain the same result. Fig. 25 shows the original form of the stern of the *Paris*.

At the time of their launch the *Paris* and *New York* were second only in length to the *Great Eastern* and the *City of Rome*. The following were their principal dimensions :—

Length over all..	560 ft.
Length on water line	525 "
Breadth	63 ft. 3 in.
Moulded depth..	42 "
Gross tonnage	10,500 tons.

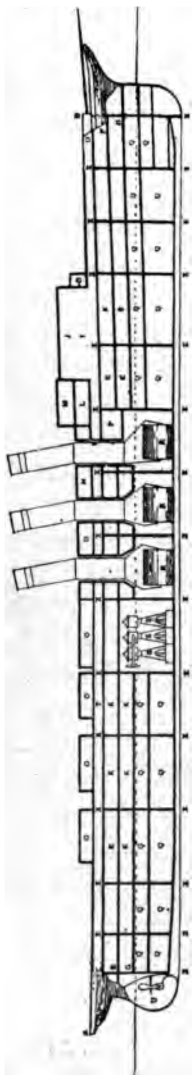


FIG. 24.—The *City of Paris*, 1888.

A.B. Promenade Deck. C.D. Saloon Deck. F.F. Upper Deck. G.H. Main Deck.
I. First Cabin Dining Saloon. J. Dome of First Cabin Dining Saloon. K. State Rooms.
L. Drawing Room. M. Bridge. N. Library. O. Promenade Deck. P. Kitchen.
Q. Cargo Compartments, Baggage and Store Rooms. R. Boilers. S. Engines.
T. Smoking Room. U. Rudder. V. One of the Screws. XXX. Watertight Bulkheads.

The hulls of these vessels are constructed entirely of mild steel, with the exception of such portions as the stern post and the original bracket frames which supported the propeller shafts, which were made of cast steel.

Fig. 24 is a longitudinal sketch section, showing the division of the hull by horizontal decks and transverse watertight bulkheads. These steamships were built to Admiralty requirements so as to be capable of serving as cruisers in time of war, and great care was bestowed upon the subdivision. It will be seen that each vessel is provided with an inner double bottom from end to end, so that no danger is likely to arise if they take the ground. The space between the inner and outer bottoms (four feet) is available for water ballast, of which 1,600 tons can be carried. The hull is divided into fifteen watertight compartments by transverse bulkheads, which are

continued upwards as far as the saloon deck, eighteen feet above the water-line. The largest of these compartments does not exceed thirty-five feet in length, and would hold 1,250 tons of water up to the normal load-line, or 2,250 tons up to the upper deck. Even if three compartments were open to the sea, the vessel would not sink, and the trim could be maintained. It has happened that vessels which have been thoroughly well subdivided have nevertheless been lost by collision, because the doors between the compartments were open at the time of the accident, and could not be closed afterwards. In the case of the *New York* and her sister ship this risk is provided against by placing the sole entrance to each compartment on the saloon deck, so that to get from one compartment to the next it is necessary to rise to the level of this deck, and to pass over the head of the adjoining bulkhead. Thus each subdivision is absolutely isolated from the others, and the spread of fire as well as of water is effectually prevented. The fourteen compartments abaft the foremost, or collision, bulkhead, are occupied in the following manner: the first three forward are given up to steerage passengers, or cargo; the next two to first-class cabin passengers; then come four which contain the boilers, the engines, and kitchens, and it should here be noted that the engine-room is divided into two watertight subdivisions by a longitudinal bulkhead, and that each group of three boilers, with the bunkers belonging to them, has a separate compartment. Immediately abaft the engine-room, the two first compartments are given up to first-class passengers, the next to second-class passengers, and the two nearest the stern to emigrants and cargo. Each compartment is fitted completely in itself, with its own lavatories, baths, toilet-rooms, etc., so that passengers are put to no inconvenience by the difficulties of intercommunication.

These vessels have five decks, each covering an area of about 27,000 square feet. The uppermost, which is reserved for the first and second-class passengers, is called the promenade deck, the spaces on either side of the deck-houses from end to end of the ship being used as promenades. Five times up and down this deck is a walk of a mile, a statement which will serve to give some idea of the size of the ship. The deck-houses contain some of the best passenger accommodation, forty rooms being here arranged *en suite.* The same arrangement obtains on the saloon deck. Promenades, 10 ft. wide, flank the deck-houses. Here are placed the principal public rooms of the ship, the most noticeable being the dining-saloon. The proportions of the dining-rooms have always been a great trouble to the designers of these large passenger vessels. As a rule, 8 ft. is the greatest height to be secured between decks, and a large room of such limited altitude is necessarily unsightly and difficult to ventilate. This difficulty was very successfully overcome in the case of the *America.* The central body of the saloon was carried up through the deck above and surmounted by a glass cylindrical dome; thus a vertical distance equal to that of three times the space between decks was obtained, and the appearance of height, so necessary to architectural effect, was realised. The same idea on a larger scale was repeated in the *New York* and her sister ship with the best result. The maximum height in the centre of the dome is 20 ft.

Great attention was paid to the lighting and ventilation. The electrical generating plant is in triplicate so as to prevent the possibility of any breakdown. The ventilation was secured by fans driven by electricity. One of the most peculiar features of these vessels is the method adopted to check rolling in a heavy sea. It consists of an iron tank about thirty-five feet long, and in shape somewhat resembling an hour glass bent

round like a horse-shoe. It is capable of holding 200 tons of water, and in practice is only half filled. Its action is as follows :—When the vessel makes a roll the water tends to flow over to the lower side. Owing, however, to the available cross sectional area of the chamber being reduced in the middle, the water does not nearly get over to the lower side by the time the roll is finished and the motion in the contrary direction commenced; it, therefore, continues to flow in the original direction till the deck of the vessel is nearly horizontal, and in consequence of its flowing against the roll of the ship it very effectually checks the pendulous motion. This device was first adopted in H.M.S. *Inflexible,* and has been carried out also in some battleships built subsequently. In later vessels, however, the more simple plan of fitting bilge keels has been found sufficient to check rolling.

The propellers of the *New York* and her sister ship are each driven by an independent set of triple-expansion engines, placed for safety in separate watertight compartments. Thus, if there is any breakdown, either in one propeller, or engine, the vessel has the remaining set to fall back upon, and even under such circumstances can be driven at four-fifths of the full speed. The general arrangements of triple-expansion engines have been described in the companion "Handbook on Marine Engines and Boilers." The leading dimensions of the triple expansion engines of the *New York* are—diameters of cylinders, 45 inches, 71 inches, and 113 inches; stroke, 60 inches; maximum horse-power, 20,000. The boilers are nine in number, divided into three groups of three. Each group, as already mentioned, is contained in its own watertight compartment, the bunkers being placed outside the boilers next to the side of the ship, so as to provide additional security against penetration by shot, or by collision. The boilers are provided with fifty-four furnaces, working under forced

draught, the fresh air being driven into closed stokeholds by powerful fans, making 400 revolutions per minute. When going at full speed the furnaces consume rather more than a ton of coal every five minutes, or 300 tons per day, the heat

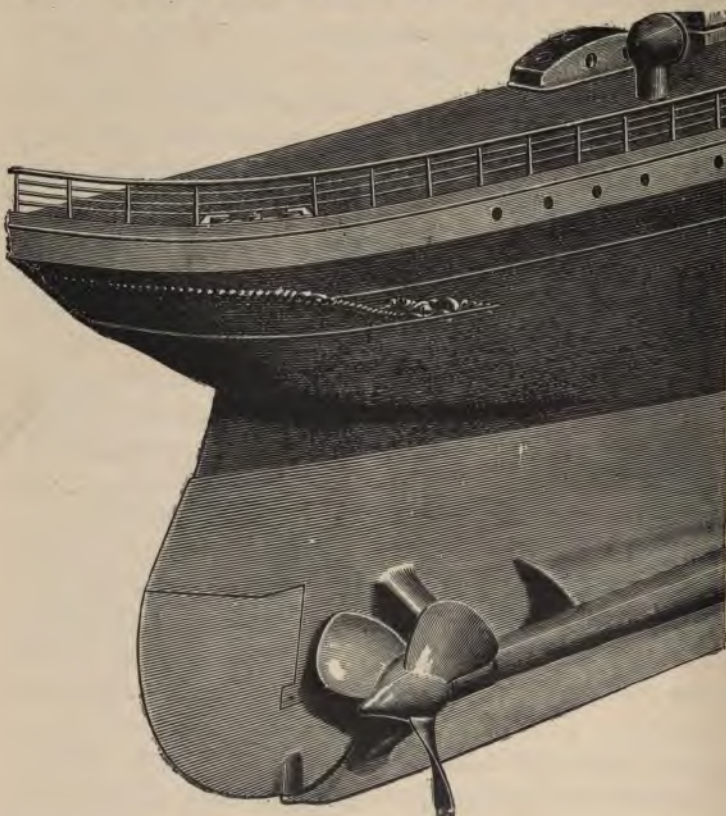


FIG. 25.—Stern of the *City of Paris.*

generated being transmitted through tubes nearly fourteen miles in length, and having an area twice that of the promenade deck. These statements will give an idea of the immense power required to drive one of these large steamers. It is

highly improbable that, with twin propellers, separate engines, and triplicated boilers, such a vessel should ever completely break down ; but, to guard against such a contingency, these steamers were fitted with three masts, and sail enough to enable them to be navigated in any ordinary wind.

The steering gear of these vessels was somewhat novel. The rudder and steering gear are entirely under water so as to be out of reach of projectiles. The rudder (Biles' patent) is of very large area, the surface of each side being 250 square feet. As may be seen from Fig. 25, it is so shaped as to be a continuation of the lines of the vessel. It is partly balanced, so as to reduce the strains both on the rudder and the steering gear ; that is to say, the axis of the pintles, instead of being at the forward end, is nearer the centre of the rudder. The steering gear consists of two hydraulic rams, placed at right angles to an ordinary tiller, one at each end. The plunger of each ram is connected to a block sliding on the arm of the tiller, an arrangement which allows the latter to take up any required angular position. The tiller is connected with another shorter tiller on the rudder head by means of a heavy cylindrical steel connecting rod, 12 in. in diameter. By means of this machinery the rudder can be put hard over when the vessel is going full speed, the thrust which each hydraulic ram can exert being 80 tons, and the strain on the connecting rod 140 tons. There are thirty-seven auxiliary engines to each vessel ; the greater number of these are hydraulic, as are also the silent hoists for loading and discharging the nine cargo holds. The maximum full speed which can be attained by these vessels continuously at sea is about nineteen knots an hour. The times of their fastest passages across the Atlantic are given on page 72.

Although these vessels are, thanks to their careful

subdivision, practically unsinkable, they are each provided with twenty-two large lifeboats having ample capacity for all on board.

The *Teutonic*, Fig. 26, and the *Majestic*, twin-screw sister ships, marked another notable advance in the construction of Atlantic liners. These vessels were built about 1889 at Belfast by Messrs. Harland & Wolff for the White Star Line. They are 582 ft. long, 57 ft. 6 in. broad, and 39 ft. 4 in. deep. The gross tonnage of each was nearly 10,000, and they were in their day the longest ships afloat. The *Teutonic* was also notable as one of the first vessels that had been built specially to comply with the Admiralty requirements as a mercantile cruiser. She was constructed to carry an armament of twelve 4·7 in. guns. The engines are of the triple-expansion type, and were designed to give 17,000 indicated horse-power, the cylinders being 43 in., 68 in. and 110 in. in diameter, respectively, with a stroke of 5 ft. There are twelve return-tube boilers working at the considerable pressure, for the time they were constructed, of 180 lbs. to the sq. inch. The total grate area of these boilers is 1,163 sq. ft.

A novel feature that was introduced in the design was the overlapping of the twin-screw propellers, which could not, therefore, be placed in the same transverse plane; and in order that they might clear the deadwood of the after part of the ship, a screw port was cut, much as in an ordinary single-screw vessel, and this allows room for the revolution of the tips of the blades. The amount of overlap is 5 ft. 6 in. These vessels were designed to carry 300 first-class, 150 second-class, and 750 steerage passengers. The main saloon is placed in the centre of the ship. The promenade deck gives, for walking exercise, a covered gallery of 18 ft. on each side of the deck-house, there being an awning deck

Fig. 26.—The *Teutonic.* 1889.

above. The saloons are most handsomely decorated and furnished in accordance with the practice of the White Star Company. The building of these ships was, to a great extent, due to the encouragement given by the Admiralty to owners to construct swift ocean-going vessels that could be converted into mercantile cruisers.

Mr. Ismay, the chief managing owner, was largely interested in the extension of this new departure in our scheme of national defence. In 1878 he urged upon the attention of the naval authorities that the fast mail, or passenger, steamer might be an efficient factor in naval warfare; and he offered to make an arrangement to hold at the disposal of the Admiralty, in time of war, certain ships belonging to the White Star Line. This suggestion was not carried out at the time, but in August, 1886, it was revived by Messrs. Ismay, Imrie & Co., when they proposed that they should build two ships, to be approved by the Admiralty, of a speed and strength superior to any merchant ship then afloat. The engines and boilers were to be below the water-line, and completely divided by bulkheads. Fittings for guns were to be built in during construction, and the ships were to be manned by crews half of which were naval reserve men. An agreement was made with the Admiralty on these lines, and the *Majestic* and *Teutonic* were constructed with a special view to war purposes in case events should render such employment necessary.

Since they were first put on the North Atlantic route these two steamers have always been favourites with Transatlantic passengers, and though they have been eclipsed in size and speed by later vessels, they have not lost in popularity. In August, 1891, the *Teutonic* made the quickest outward passage accomplished up to that time, having steamed 2,778 nautical miles in 5 days 16 hrs. 31 mins. In doing this she beat the previous fast passage of

the *City of Paris* on the same route made in September, 1889, when the time was 5 days 19 hrs. 18 mins. for 2,788 miles. In October of the same year (1891) the *Teutonic* also took the first place for speed on the homeward voyage, having made the run of 2,790 miles in 5 days 21 hrs. 3 mins. The *City of Paris* in December, 1889, had covered 2,784 miles on the homeward run in 5 days 22 hrs. 50 mins.

Passing by various vessels important in their day, the next steamers to be noticed as showing considerable and distinct advance were the two large Cunard liners *Campania* and *Lucania*. These vessels were commenced in the year 1891; the *Campania* was launched on 8th September, 1892, and the *Lucania* on 2nd February of the following year. An illustration of the *Lucania* is given in Fig. 27. The builders of both the hulls and engines were the Fairfield Shipbuilding and Engineering Company of Glasgow. The following are the leading particulars of these two ships :—

Length over all	622 ft.
Length between perpendiculars	600 „
Extreme breadth	65 „ 3 in.
Depth from upper deck	41 „ 6 „
Depth from shade deck	59 „ 6 „
Gross tonnage (about)	13,000 tons.

It will be seen, therefore, that these new vessels exceeded the White Star vessels the *Teutonic* and *Majestic* in length, while the breadth was greater by about 8 ft. This is in accordance with the traditions of the two lines, the late Sir Edward Harland, who designed all the White Star vessels up to the time of his death, having been a strong advocate of long and relatively narrow ships. It may be noted in connection with this subject that the *Campania* and *Lucania* are absolutely longer than the width of the Clyde at the part where the Fairfield shipyard is situated, and the

Fig. 27.—The *Lucania*. 1893.

vessels had to be launched diagonally to the course of the river. They are propelled by twin screws, and some novel features were introduced in the construction for the support of the propellers and shafting, the great advances made in steel castings having been utilised to the fullest extent. The engines are of the triple-expansion three-crank type, developing no less than 30,000 indicated horse-power as against 17,000 of the *Teutonic.* Each set of main engines has five cylinders, two of them being high-pressure, one intermediate, and two low-pressure, the high-pressure cylinders being placed tandem-wise above the low-pressure cylinders. The diameters of the cylinders are 37 in., 79 in. and 98 in., by 69 in. stroke. There are in each ship twelve large return-tube boilers, and two smaller ones for auxiliary purposes. The total number of furnaces is 102. The main boilers are double-ended, 18 ft. in diameter and 17 ft. long. The funnels are 120 ft. high and 20 ft. in diameter. The average speed on the return journeys from New York taken over a twelve month was, in the case of the *Campania,* 21·88 knots, and in that of the *Lucania* 20·01 knots.

A notable feature in the building of these ships was the large size of the plates used in their construction. The standard dimensions laid down for the shell plates were length 25 ft. by width 6 ft., the weight being about 2 tons. In some cases, however, the width of the plates is nearly 8 ft., and the thickness varies from ¾ in. to 1 in. The use of plates of this great size was due to the advance made by the steel makers in rolling-mill practice. These large dimensions much facilitated the work of construction, and, naturally, saved a considerable amount of riveting. The frames are of channel section in place of the older type of angle and reverse angle, the construction being

strengthened at intervals by deep web frames, especially in the neighbourhood of the machinery spaces. Another new feature was the use of a completely plated steel promenade deck. A midship section in sketch is given at Fig. 70, page 152. As these vessels were built to meet the Admiralty specification as mercantile cruisers, special arrangements were introduced in order to keep the rudder head below water line. They are subdivided by means of sixteen complete bulkheads which will enable them to float if two, or, in some cases, even three, compartments are pierced. Passenger accommodation was arranged for 600 first-class, 400 second-class, and 700 to 1,000 third-class passengers. In these ships the first-class passenger accommodation is placed in the centre of the vessel, the dining saloon being on the main deck; this saloon is of large size, being 100 ft. in length by 62 ft. in width, and can seat 430 passengers. The central portion is 33 ft. high, passes through two decks, and is surmounted by a crystal dome. An illustration of this splendid hall, for it is no less, is given in Fig. 28. The dining-room is intended to be used exclusively for meals, there being, in the drawing-room, library and smoking-room, accommodation for all first-class passengers even in bad weather, when it is necessary to keep them under shelter. Fig. 29 is a view of a corner of the first-class smoking-room, and will serve to give an idea of the luxurious furnishing of these ships. It will be noticed that this room, and in fact all the principal rooms of these vessels, are provided with open fire-grates. The second-class dining-room, smoking-room, etc., are placed on the upper and the promenade decks. The steerage passengers are berthed on the lower, but they have a promenade on the upper deck.

FIG. 28.—Saloon of the *Campania*.

FIG. 29.—A corner of the smoking-room of the *Campania*.

CHAPTER V.

FURTHER EXAMPLES OF MODERN PASSENGER STEAMERS.

WITH the *Campania* and *Lucania*, the Cunard Line for some time held what has been described as the "blue ribbon" of the Atlantic, but in 1898 there was built a vessel which took from Great Britain the supremacy in ocean speed which she had, till then, held. The steamship that achieved this notable feat was the North German Lloyd's Atlantic liner the *Kaiser Wilhelm der Grosse*, built by the Vulcan Company of Stettin. She was, at the date she was launched, the largest ship in the world, and soon proved herself to be the fastest ocean-going vessel. She is mentioned here, in order to preserve chronological order; but, as a still larger and more powerful ship—the *Kaiser Wilhelm II.*—belonging to the same company will be described later on, it will now be sufficient to give only the leading elements of design. They are as follows:—

Length over all	648 ft. 7 in.
Length between perpendiculars ..	625 „
Breadth	66 „
Depth (moulded)	43 „
Gross tonnage	14,349 tons.
Draught	28 ft.
Displacement	20,800 tons.
Number of passengers (first class)	590
„ „ „ (second class)	354
„ „ „ (third class)	640
Type of engine	4-cylinder, triple-expansion.
Number of cranks	4
Diameter of cylinders ..	52″, 87·9″, and two of 96·4″.

Stroke	68·8″
Boilers..	12 double-ended, 2 single-ended.
Number of furnaces..	104
Steam pressure	178 lbs.
Total heating surface	84,285 sq. ft.
Grate area	2,618 „ „
System of boiler draught	Open stokehold.
Total indicated horse-power ..	30,000
Highest mean speed on Atlantic passage	22·79 knots.
Designed speed	22·5 knots.

As will be seen by the above particulars, this fine vessel bore out the anticipations that had been formed for her. She made the speed of 22·79 knots on one of her early voyages, and she rapidly became one of the favourite ships of the route.

It has been found in practice that speed is one of the chief elements of success in an Atlantic liner, the public generally preferring the fastest ships, often as much from the prestige attached to these vessels as from the necessity for saving time. On the other hand an enormous price has to be paid for these high speeds, the last few knots requiring an inordinate addition of power for their attainment. This question is referred to again on page 90.

The next step in the progress of ocean navigation was made by the White Star Company, who ordered from Messrs. Harland & Wolff, of Belfast, a vessel that was even larger than the *Kaiser Wilhelm der Grosse*, although not designed to attain so high a speed. This was the *Oceanic*, the second of the name. An illustration of this ship is given in Fig. 30. She was launched in January, 1899, and was then the longest vessel that had ever been built. Even the length of the *Great Eastern* was exceeded, for that great ship was 692 ft. over all, whereas the *Oceanic* is 705 ft. True to the builder's traditions, however, the *Oceanic* was considerably narrower than the *Great Eastern*, the latter vessel having been

FIG. 30.—The second *Oceanic*. 1899.

83 ft. wide, while the *Oceanic* was but 68 ft. 3 in. The following are the chief elements of design of the *Oceanic* :—

Length over all	705 ft.
Length between perpendiculars ..	685 „
Breadth	68·4 „
Depth (moulded)	49 „
Draught maximum	32 ft. 6 in.
Gross tonnage	17,274 tons.
Displacement at above draught ..	28,500 tons.
Number of passengers (first class)	410
„ „ „ (second class)	300
„ „ „ (third class)	1,000
Type of engine ..	two sets of 4-cylinder, triple-expansion.
Number of cranks	4
Diameters of cylinders ..	47·5″, 79″, and two of 93″.
Stroke	72 in.
Boilers	15 double-ended.
Number of furnaces..	96
Steam pressure	192 lbs.
Total heating surface	74,686 sq. ft.
Grate area	1,962 „ „
Draught (system)	Assisted draught.
Total indicated horse-power ..	27,000
Highest mean speed on Atlantic passage	20·7 knots.

Fig. 31 is a sketch of the midship section of the *Oceanic*, from which it will be seen how widely she departs from the design of the older ships, such as the *Great Eastern* (see Fig. 69, page 149); the flat floor and sharp turn of the bilge producing a figure which is almost a rectangle. The rise of floor amidships is about 2 ft. and the tumble home of the sides about 1 ft. Her launching weight was 11,000 tons; and the weight of the full structure when finished was about 12,000 tons.

The vessel has, as will be seen from the cross section, seven decks in all, though the uppermost, or boat deck does not extend the whole length of the vessel, but reaches only from the captain's bridge to the engine-room skylight. The captain's bridge is no less than 40 ft. above the surface of the water,

The lower orlop deck does not extend the whole length ; there are, however, five decks which are continuous from stem to stern. All decks and partial decks are completely plated, and thus add greatly to the strength of the hull structure.

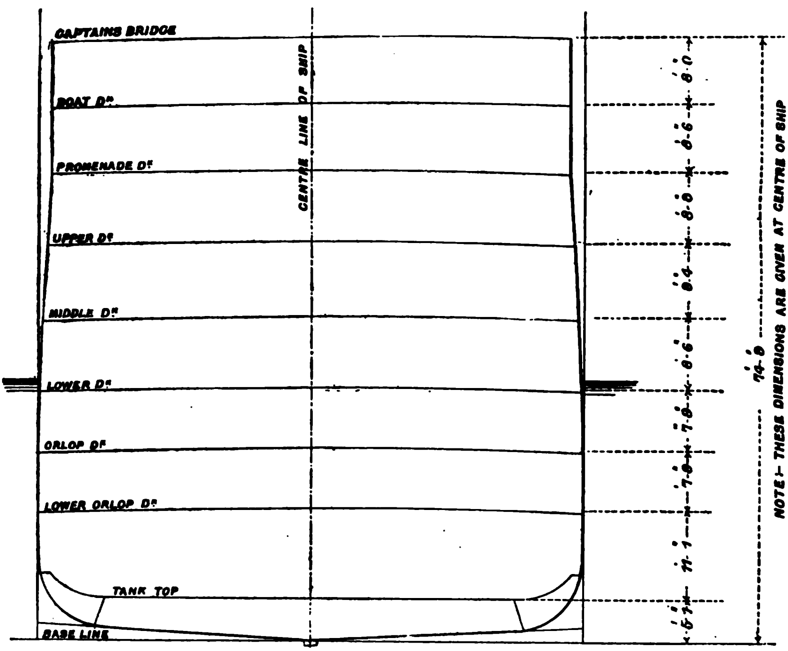


FIG. 31.—Sketch of Midship Section of the *Oceanic*.

In the design of the *Oceanic* great care was taken to make all parts of the structure contribute to the strength of the hull. The cellular bottom, Fig. 32, with its deep inner keel and longitudinal girders, the steel decks, and the doubling of the plating at bilges, upperdeck and sheer-strakes, all contribute to this end. Reference should be made to the way in which the

various parts were put together; for, without care in this respect, the mere provision of material for strength would be useless. The doubling of the plating, and the use of an outer keel bar, necessitated unusually large rivets, which it would have been extremely difficult, if not impossible, to have closed by hand. Riveting by hydraulic-power machines for ship work was, of course, well established practice long before the day of the second *Oceanic*. There are certain positions in the ship where it is very difficult to introduce the hydraulic riveter, and at these, the additional security due to the use of this machine is not obtained. Some of the rivets in the *Oceanic* were from 6 in. to 6½ in. long, a few even up to 7 in.

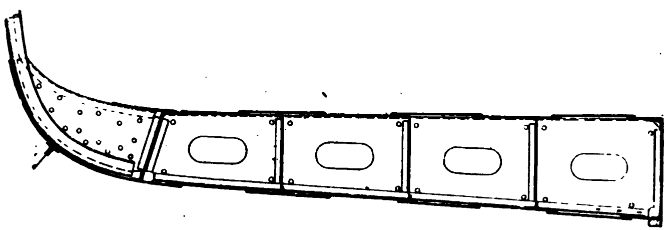


FIG. 32.—Section of double bottom of the *Oceanic*.

The hydraulic riveting machines used for the exceptional work mentioned were larger than any up to that time employed for these positions, some of them having been 7 ft. deep in the gap in order to reach the rivets furthest from the edge of the plates. Such machines were too heavy to handle in the usual way, and, therefore, a vast travelling gantry was constructed from which the riveting machine could be slung. Two lines of heavy railway were laid on the ground, one on each side of the ship. The uprights of the gantry were mounted on wheels and the tops of these two vertical members of the structure were connected by a horizontal girder, or bridge; the various machines used were slung from the latter. The whole gantry thus straddled the ship, and was capable of

being moved bodily from end to end of the slip-way. It reached to a height of 96 ft. and a width of 95 ft. beneath the cross girders and between the standards. This large gantry was a massive and costly structure, and though it greatly helped the progress of the work it was somewhat cumbersome to move, and was only available for one position at a time. A more modern, and more flexible system, is that of erecting a fixed overhead gantry above the whole length of the ship, fitted with several electric cranes travelling on a runway. By this arrangement work can proceed simultaneously in many positions.

One great advantage of hydraulic riveting is that the full pressure can be kept on the rivet until the latter is cold, and, therefore, no longer liable to stretch. The contraction of the rivets keeps the parts in close contact, and the friction set up when, in a sea way, the plates tend to slip on each other, is an important element of strength in the structure.

It will serve to give an idea of the magnitude of operations in the building of modern steamships if one or two details of weights involved in the construction of the *Oceanic* are mentioned. The weight of the rudder is 53 tons. The total weight of the stern post, rudder and arms supporting the ends of the propeller shafts is 150 tons; about equal to that of a small coasting vessel. In addition to this there are the two 3-bladed, 22 ft. diameter propellers and their shafts which have to be carried by the after part of the ship. The stem consists of a massive steel casting, and each of the hawse pipes is a single steel casting weighing 7 tons. The weight of the after boss-arms supporting the propellers is 42 tons, and that of the forward boss-arms 23 tons. It may be interesting to note that, at the time of launching, it was stated that 1,704,000 rivets had been used in the construction

FIG. 33.—Main saloon of the *Oceanic*.

of this ship, some of them being 3½ lbs. in weight. In the construction of the *Great Eastern* 2,000,000 rivets were used. It must be remembered that the steel plates of the *Oceanic* were very much larger than those of the older vessel, and thus fewer joints were needed.

The *Oceanic* was expressly designed for use as an auxiliary cruiser; the extra strengthening for gun positions and other features of a like nature were incorporated in the structure.

The library, smoking-rooms, drawing-room and other saloons for first-class passengers are highly decorated. Their general design was prepared by Mr. R. Norman Shaw, R.A. The main saloon, illustrated in Fig. 33, is 80 ft. long by 64 ft. wide, and is arranged to seat 350 persons. In the centre of the saloon is a raised trunk, 21 ft. square, extending through the upper deck in the form of a glass dome which partly projects through the promenade deck. This feature was previously introduced in the *America* and the *City of Paris*, as already stated, and is now common in many large ocean liners.

Although a first-class ocean-going passenger vessel in every respect, regarding build, equipment and the highest class of passenger accommodation, the *Oceanic* was not intended to break the record of the Atlantic; her engine power not being sufficient to attain this end. The policy of aiming only at a lower speed than that which had been already reached was deliberately adopted by the late Mr. Ismay in ordering the vessel. The White Star vessels leave Liverpool on Wednesday afternoon, and are timed to arrive in New York Harbour early on the following Wednesday morning. Mr. Ismay's view was that so long as the *Oceanic* might be confidently counted on to land her passengers at eight o'clock on the Wednesday morning following their departure, enough was achieved for all practical purposes. To reduce the time of

the voyage by twelve hours would have necessitated a very great increase in the engine power; and not only would this have been expensive, but would have led to the ship being wet and uncomfortable in a heavy sea, besides increasing the vibration. The latter is one of the most unpleasant features in many high-speed ships, notwithstanding the great advances that have been made in the balancing of engines. It has been calculated that to gain twelve hours on the voyage to New York would have added about 30 per cent. to the power, and nearly 20 per cent. to the coal bill, while it would have reduced the freight-earning capacity by nearly 40 per cent. Such a saving in time, however, would not have been a great advantage, as the vessel would probably not have arrived in time to disembark her passengers at New York on the previous evening, and they would, therefore, have had to wait for the morning to land. Thus there would have been little prospect of gain from even a very considerable increase of engine power.*

As this is the last of the high-speed White Star liners to which reference will be made, a few words may be said on the general features of the design of the ship. The comparatively small beam, low bilge, and long middle body, carried well forward and aft, that have characterised the celebrated Belfast ships, were elements of design with the first vessels built by the late Sir Edward Harland, over thirty years ago. That the form is a good one for speed has been proved by years of service, and it is equally certain that it permits of a safe type of ship. The *Oceanic* carries her full width approximately over about half the length of the vessel, the form of the midship section being little departed from for an unusual distance of the

* It was stated unofficially that on her trial the speed attained by the *Oceanic* did not exceed 22 knots.

FIG. 34.—The *Kaiser Wilhelm II.* 1903.

middle body. Like in all other White Star liners, there is a straight stem, but the *Oceanic* differs from some of the earlier ships of her class in not having turtle-back decks forward and aft. It was stated that these somewhat unsightly structures were introduced by Sir Edward Harland as a concession to those who considered long and narrow ships dangerous. Many shipowners and naval architects will remember the outcry that was raised when Sir Edward Harland first cut down beam in designing steamers for the Bibby Line. Tank experiments have shown that the beam may be increased, if the ends of a ship are fine, without loss in speed; but, it should be remembered that tank experiments are made in smooth water, where the effect is very different to that of the plunging of a fine-ended ship in a sea-way. As a matter of fact, the White Star steamers have been always good time-keepers in stormy weather.

Another feature in the *Oceanic* which has been characteristic of the White Star vessels, and has been followed in other designs, is the cutting away of the fore-foot in order to give good manœuvring powers. In steamers of great length this practice puts them more on an equality with shorter vessels in regard to quickness of turning. The feature is well shown in the bow view of the *Celtic* as she appeared on the stocks, Fig. 41, facing page 96.

We now pass to a vessel which, at the present time (1906) may be justly described as one of the highest achievements in ocean navigation. The ship in question, the *Kaiser Wilhelm II.*, is illustrated in Fig. 34, facing page 82. She is the most important vessel in the fleet of the Norddeutscher Lloyd Company, and was built at the Vulcan Works in Stettin for the voyage between Bremen and New York. She is, like most high-class liners of modern build, a twin-screw vessel, and is, approximately, of the same length as the *Oceanic*, but is a

broader and deeper vessel, so that her gross tonnage is 2,726 tons in excess of that of the White Star ship. She is much more powerfully engined and faster than the latter vessel, and indeed, at the time of writing holds the highest record for speed of any ocean liner, having wrested the first place from the *Deutschland* on her voyage from New York to Plymouth in June, 1904. The latter ship is the property of the Hamburg American Company, and was also built at the Vulcan yard.

The following are the chief particulars of the *Kaiser Wilhelm II.* :—

Length over all	.. 706 ft. 6 in.
Length between perpendiculars ..	.. 688 ,,
Breadth	.. 72 ,,
Depth (moulded)	.. 44 ,, 2 in.
Height from keel to navigating bridge	.. 88 ,, 7 ,,
Gross tonnage	..20,000 tons.
Draught	.. 29 ft.
Displacement (at 29 ft. 6 in. draught)	..26,500 tons.
Number of passengers carried (first class)	.. 775
,, ,, ,, ,, (second class)	.. 343
,, ,, ,, ,, (third class)	.. 770
Type of engines (4 sets)	Quadruple expansion.
Diameter of high pressure cylinders	.. 37·4 in.
,, ,, first intermediate cylinders	.. 49·2 ,,
,, ,, second intermediate cylinders	.. 74·8 ,,
,, ,, low pressure cylinders	.. 112·2 ,,
Stroke	.. 70·8 ,,
Number of boilers (return tube) ..	.. 19
Steam pressure	.. 225 lbs.
Revolutions	.. 80 per minute.
Total heating surface	..107,643 sq. ft.
,, grate area	.. 3,121 ,, ,,
System of boiler draught	Open stokehold.
Total maximum indicated horse-power	.. 45,000
Highest mean speed on Atlantic passage	.. 23·6 knots.
Designed speed	.. 23 knots.

When working at full power her consumption of coal is said to be from 650 to 700 tons a day. This would be

FIG. 35.—Main saloon of the *Kaiser Wilhelm II.*

about 200 to 250 tons a day greater than the consumption of the *Oceanic*. The *Kaiser Wilhelm II.* has in all eight decks. There is in the central length a raised superstructure, as will be seen from the illustration. It comprises a deck house 443 ft. long, the roof of which runs from side to side of the ship, thus overhanging the deck house itself. This roof constitutes a promenade deck, which, being extended at the ends, is 538 ft. long. On this promenade deck there is another upper deck house 438 ft. long. The deck presents a very lively aspect on a fine morning, or afternoon, at sea when it is crowded with passengers. It is the favourite lounge where chairs are placed, while the lower spacious promenade deck is used more especially for exercise. In this vessel access is also given to the boat deck, which, necessarily, is the top deck of all, and passengers may therefore sit with nothing but the sky above them--a great boon in fine weather. Passengers are also admitted to the two 'thwartship galleries forward, at the ends of the promenade decks, but with a steamer travelling at 23½ knots these positions are somewhat exposed, unless a strong leading wind happens to be blowing; a more sheltered place is the open-ended smoking *café*, which is in the corresponding position aft, where there is nearly always still air. The first-class accommodation is largely above the moulded part of the hull, that is to say in the superstructures mentioned, where ports can nearly always be kept open.

The floating population of this ship is about 2,500 persons when she has a full number of passengers, including the ship's company of about 600. Amongst the latter there are 45 in the deck complement, 227 in the engineering department, 170 stewards and stewardesses, and 61 cooks and assistants. Like all modern steamers of large size, the vessel is fitted throughout with electric light. There are 28 bath rooms

for general use besides those attached to the special suites of rooms. Telephones are fitted for the use of the ship's company. There are 52 watertight doors in the bulkheads which divide the vessel up into a number of separate compartments, any two of which might be filled without sinking the ship. A number of these doors can be closed from the bridge by means of a special device. There is in the chart-house an indicator showing which doors are open, or closed. The pumping arrangements provide for ejecting 9,360 tons of water per hour. The windlasses and capstans were supplied from Great Britain, and the chain cables are 3½ in. in diameter.

The twin-screws are each four-bladed, and are 22 ft. 9 in. in diameter. The propeller shafting is of crucible steel and is 25½ in. in diameter. The number of separate steam engines on board is 79, the number of cylinders being 124. The launching weight of the ship was 11,200 tons.

The first-class saloons of the *Kaiser Wilhelm II.* are very highly decorated. The main dining-room is shown in Fig. 35. It is situated on the main deck and extends from side to side of the ship, there being seating accommodation for 554 persons. In the central part it extends upwards through two decks above, and is surmounted by a top-lighted dome. The chief smoking-room, one end of which is shown in Fig. 36, and also all the other public rooms, are handsome apartments.

No higher speeds on an ocean voyage have yet been attained (1906) than those reached by the *Kaiser Wilhelm II.* and the *Deutschland*, but there is a fair prospect that Great Britain will resume her old position when the turbine engined vessels which are now being constructed for the Cunard Company on the Clyde and Tyne are put on their station. They are expected to steam at a speed of 25 knots ;

FIG. 36—Smoking-room of the *Kaiser Wilhelm II.*

what they will reach is problematical, the design being so novel and the conditions so unprecedented. When these vessels were projected there had been practically no experience with large turbine engined Transatlantic boats to guide their constructors. In the early part of the year 1905, however, two steamers of this category fitted with turbine engines, viz., the *Virginian* and *Victorian*, of the Allan Line, commenced regular work. At the end of the same year the *Carmania*, of the Cunard Company, also fitted with turbine engines, made her first voyage across the Atlantic, and fulfilled the expectations of her designers. A description of the *Carmania* will be found on pages 93, 94, 167 *et seq.*

The following are the principal data of these great ships, which are to be named the *Lusitania* and the *Mauritania*:—

Length over all	785 ft.
Breadth	88 „
Depth (moulded)	60 „ 6 in.
Draught (extreme)	36 „
Height from keel to boat deck	90 „
Displacement at draught of 33 ft. 6 in. ..	40,000 tons.
Number of passengers (first class)	550
„ „ „ (second class) ..	500
„ „ „ (third class)	1,300
„ „ crew	800
Power of engines	about 70,000 I.H.P.
Number of screw-propellers	4
Number of boilers	equivalent to 24 double ended.

There will be four sets of main turbines, driving as many shafts for steaming ahead, and two sets for going astern.

The great breadth of the ship will allow room for four boilers being placed abreast athwartship, with ample space for bunkers in the wings. There will be eight partial and continuous decks in all, as follows:—The orlop deck, on which the ship's stores are carried; the lower deck, on which third-class passengers are to be accommodated in a style never before contemplated; this deck will be above the water

line; the third or main deck, on which the first-class state rooms are located; and the fourth or upper deck, which contains additional first-class accommodation, and also the floor and lower part of the great dining-saloon, which will be 125 ft. long and as wide as the ship. The fifth, or shelter deck will be the upper structural deck of the ship. The hull plating is carried up to this deck, but the three decks above it, viz., the bridge, boat and promenade decks, are not part of the hull structure proper, but are built upon it.

It should be noted that these ships can only be loaded to their full draught of 36 ft. when the new channel into New York Harbour has been fully dredged.

The cost of these vessels has not been made public, but it is understood that it will approximate to £1,500,000 for each ship, and the Government has advanced to the owners, at the moderate interest of 2¾ per cent. per annum, the sum of £2,600,000. An enormous horse-power, to secure speeds unprecedented in ocean passenger steamers, will be the dominant feature of these vessels. They cannot possibly be remunerative in the ordinary sense, and each of them will receive a Government subsidy of £75,000 a year.

Fig. 37 illustrates in graphic form the growth in size of Atlantic steamers since the foundation of the Cunard Company.

The table which forms Appendix III. gives particulars of the most remarkable Transatlantic liners since the introduction of steam on this service. It shows how great is the increase in power and, consequently, in fuel consumption and how large a proportion of the total displacement is absorbed in the weights of propelling machinery, boilers, and coal when high speeds are aimed at. To the non-technical reader it may not be at first apparent why high speed should involve the exertion of so much power. It might appear natural to him that, if a given ship attains the speed of 15 knots by

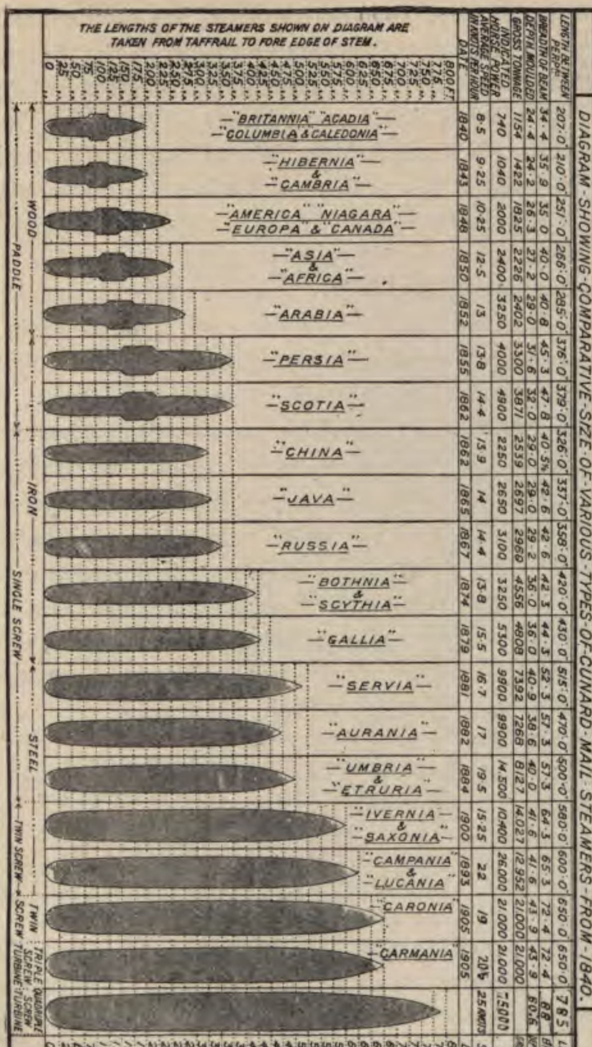


FIG. 37.—Diagram showing Development of Cunard Steamers.

the exertion of, say, 9,000 horse-power, she should attain a speed of 20 knots by increasing the power in the proportion of 15 to 20, that is to say to 12,000 I.H.P., whereas experience shows that a much higher power has to be exerted. The explanation of this state of things depends partly upon the laws of the resistance to motion of floating bodies, a subject which is not suitable for treatment in this handbook. It is sufficient to state generally that the resistance of ships increases much more rapidly than in direct proportion of the speed. At comparatively low powers the increase is in proportion to about the square of the speed, while at very high powers it may increase as rapidly as the 5th power. The subject is further complicated by considerations affecting the resistances of the engines and propellers and the consequent ratio of actual to effective horse-power at different speeds.

Strict comparisons of the powers required to attain different speeds can only be made by carrying out progressive trials on a vessel under conditions which are identical except so far as they relate to horse-power; but the following table, though not compiled for vessels of the same size, will illustrate the point. The figures are not official.

Name.	Length B. P.	Displacement.	Speed.	I.H.P. at given Speed.	Coal per day.	Coal per 100 knots.
	Feet.	Tons.	Knots.		Tons.	Tons.
Kaiser Wilhelm II.	688	26,500	23·25	45,000	650	116·4
Oceanic	685·7	26,100	20	29,000	400	83·3
Caronia	650	30,900	18	20,000	320	74·0
Saxonia	580	20,500	15·5	10,400	140	37·9

The ever-increasing first cost, and the ever more rapidly advancing expense of running these fast steaming and splendidly equipped Atlantic liners, led owners to cast about for a more paying type of vessel. It was recognised that size was essential for comfort in order to lessen the effect of the waves and to afford more spacious accommodation.

FIG. 38.—The *Ivernia* 1899.

High speed, however, is sometimes an element of discomfort, for the powerful engines necessary for its attainment, unless carefully balanced, lead to vibration. Moreover, the value of speed to the majority of passengers is mainly that it limits the duration of an experience that is sometimes unpleasant. In large comfortable ships, however, the most unpleasant features of ocean travelling have disappeared. Hence speed has become of less importance in steamers that do not carry mails. Another and a most important consideration relates to freight. In the high speed liners such a large proportion of total displacement is absorbed in the weight of engines, boilers and fuel that the cargo-carrying capacity is extremely limited. The information given on the table, Appendix III., clearly brings this point out.

These considerations led to the introduction of what has become known as the class of "intermediate ocean liners," a large, relatively low powered type of ship. It was thought that many passengers would sacrifice time to comfort, and magnificence to economy. The result has proved the wisdom of this forecast. In 1899 the Cunard Company built the *Ivernia* and the *Saxonia*, of about 14,000 tons gross, and capable of carrying 12,900 tons dead weight on 32 feet draught. Their average speed is 15 to 16 knots, and the indicated horse-power about 10,400. In running on actual service they consume 140 tons of coal a day on a mean displacement of 20,500 tons. The *Ivernia* was constructed on the Tyne, by Messrs. Swan & Hunter, of Wallsend. In Fig. 38 we give an illustration of this vessel; and in Fig. 39 a view of her main saloon. The *Saxonia* was built at Clydebank. Their principal dimensions are: length between perpendiculars 580 ft., breadth 64·3 ft., depth 41·6 ft. The engines of these ships were designed with a special view to economy in steam consumption. When tested by the Admiralty

boiler committee it was found that they only consumed 13·4 lbs. weight of steam per I.H.P. per hour, while the boilers evaporated 11·3 lbs. of water per lb. of fuel. The consumption of fuel per I.H.P. was, therefore, only 1·29 lbs. per hour.

The White Star Line also possesses some "intermediate" vessels. The *Celtic* and *Cedric*, of 20,000 tons gross and about 32,000 tons displacement on 32 ft. draught, were laid down at Belfast. The *Cedric* at the time of her launch was the largest ship afloat. Her length between perpendiculars is the same as that of the *Great Eastern*, 680 ft., but she is 8 ft. narrower than the latter vessel was, being 75 ft. If she could be laden to her full draught of 36 to 37 ft. she would displace 37,000 to 38,000 tons. The *Great Eastern* displaced roughly 30,000 tons. Since the *Celtic* and the *Cedric* have been on the North Atlantic route a still larger "intermediate" ship, the *Baltic*, has been added to the White Star Company's North Atlantic fleet, and this vessel is at the present time the longest ship actually working, and will remain so until the Cunard liner, the *Lusitania*, is completed. She is 708 ft. long between perpendiculars, 75 ft. 6 in. wide, and 49 ft. deep. Her capacity for measurement cargo is 28,000 tons, and she will accommodate nearly 3,000 passengers, while her crew will number 350. She is 24,000 tons gross, and her displacement is over 2,000 tons greater than the *Cedric*. She was designed for a speed of about 15½ to 16½ knots. Her engines, which are of the quadruple expansion type, indicate about 16,000 horse-power. The *Baltic* is, it will be seen, longer than the *Great Eastern* was, but is 7 ft. 6 in. less in width, and is also less in moulded depth.

Fig. 40 is an illustration of the *Celtic* afloat, and Fig. 41 shows her forebody while on the stocks. The other two vessels are similar in general design. Fig. 42 shows the *Baltic*.

FIG. 39.—Main saloon of the *Ivernia*.

The *Kaiser Wilhelm II.* of the North German Line, and the *Baltic*, of the White Star Line, represent the highest achievements in ocean navigation at the time of writing. They are types of two distinct classes, each of which has its advantages. The *Oceanic* may be in some respects classed as between the two; she having been deliberately designed, as already stated, for a lower speed than the maximum then reached, and was intended to carry about 5,000 tons of cargo, in addition to her bunker coal of 3,000 tons.

The *Caronia* and *Carmania* are the last vessels of the intermediate type to be described. They were built by Messrs. John Brown & Company at their Clydebank works for the Cunard Company and are, in many features, reproductions of the *Saxonia* and *Ivernia*, but on a much larger scale. These ships, one of which is illustrated in the Frontispiece, are of peculiar interest at the present time (1906) as the *Caronia* is fitted with ordinary quadruple expansion engines and twin screws, while in the *Carmania*, the propelling machinery consists of three turbines driving as many screws for going ahead, and a reversing turbine fitted to the central shaft for going astern. In other respects they are sister ships, and as they are both employed on the same service,* their working will afford a most valuable comparison between the merits of the two types of machinery. The following are the principal dimensions and other data of these ships :—

Length between perpendiculars	650 ft.
Length over all	672 ft. 6 in.
Breadth, moulded	72 ft.
Depth, moulded	52 ft.
Depth from manœuvring bridge to keel ..	90 ft.
Draught in working condition	33 ft. 3¼ in.
Gross register tonnage	19,524 tons.

* The *Caronia* early in 1896 was transferred to the Mediterranean service.

Displacement in working condition ..	..	30,918	tons.
Weight of steel used in constructing hull	..	12,000	,,
Weight of cargo	over	10,000	,,
Number of passengers (first-class) ..	..	300	
,, ,, ,, (second-class) ..	..	326	
,, ,, ,, (third-class) ..	..	1,060	
,, ,, ,, (steerage) ..	..	1,000	
,, ,, officers and crew	..	710	

The cylinders of the quadruple engines of the *Caronia* have the following diameters: High pressure, 39 in.; first intermediate, 54½ in.; second intermediate, 77 in.; low pressure, 110 in.; stroke, 5ft. 6 in.; length of connecting rod, 12 ft. The turbine machinery of the *Carmania* shows a saving in weight of 5 per cent. over the reciprocating engines of the sister ship. There are eight double ended, and five single ended boilers in each vessel, fitted with Howden's system of forced draught. The steam pressure is 210 lbs. in the case of the *Caronia*, and 195 lbs. in the *Carmania*, in the boilers, while the engines take their steam at the pressure of 200 lbs. and the turbines at 195 lbs. The engines of the *Caronia* indicate 21,600 H.P. and are, like those of the *Saxonia*, of a very economical type (*see* page 91). The area occupied by the machinery is the same in each ship. On their trial trips, with both their bottoms somewhat foul, the *Caronia* attained a speed of 19 knots on the measured mile, the engines developing 21,600 H.P., while the *Carmania* attained a speed of 20·19 knots. With clean bottom the *Caronia* made an additional half knot, so it is to be presumed that the sister ship will in similar condition attain a speed of at least 20·6 knots. The *Carmania* has made several successful voyages across the Atlantic. A description of the structural arrangements of the hulls of these vessels will be found on pages 167 to 170.

It is only those who are old enough to have made a voyage in one of the earlier steam vessels who can fully appreciate the

FIG. 40.—The *Celtic*. 1901.

luxury of a modern Transatlantic liner. The comfort that comes with ships of great size at sea is chief of the advantages to the average landsman. It does not need a naval architect, or a sailor, to appreciate the fact that the effect of ocean waves in producing discomfort is largely governed by the size of the ship, relatively to that of the waves. As a matter of fact, with the largest vessels the action of the sea is hardly noticed unless the weather is very bad. This applies less with a beam sea; but, the fitting of bilge keels has greatly reduced rolling; in fact, the ocean voyage on the largest vessels may fairly be said to have been robbed of its terrors to all but the most sensitive.

Among those to make a voyage across the ocean in the early days of Transatlantic steam navigation was Charles Dickens, and he has left an eloquent account of the discomforts of that era. In the year 1842 he crossed from Liverpool to Boston in the *Britannia* (Fig. 14 page 24), one of the first of the Cunard ships; and it is suggestive of the value of the accommodation then provided that he returned some months later in a sailing vessel. The state of things recorded in the description of his impressions stands in vivid contrast with the conditions of comfort now prevailing. "Before descending into the bowels of the ship," he says, "we had passed from the deck into a long, and narrow apartment not unlike a gigantic hearse with windows in the sides; having at the upper end a melancholy stove, at which three or four chilly stewards were warming their hands; while on either side, extending down its whole dreary length, was a long, long table, over each a rack, fixed to the low roof, and stuck full of drinking-glasses and cruet-stands, hinted dismally at rolling seas and heavy weather."

Making some allowance for the nervous depression of a landsman about to enter upon an enterprise at sea, the dangers

of which were imperfectly appreciated, but with discomforts that were certain, the description brings back forcibly the experiences of those early days. If Charles Dickens, in his despondency at the prospect of the voyage, could compare the saloon of the *Britannia* to the inside of a hearse, we may, without exaggeration, liken the saloons of our best ocean liners to the halls of kings' palaces, indeed, the halls of many royal abodes are dingy and confined compared to the principal apartments of such ships as the *Oceanic*, or the *Campania*, while the saloon of the *Kaiser Wilhelm II.*, as shown in Fig. 35, resembles nothing so much as a handsome theatre.

The other accommodation provided for passengers is on a like scale. The smoking-room in the older ships was hardly more than a cuddy on the deck, to be ventilated by leaving the door open ; now it is an apartment of noble proportions such as would be a credit to a modern high-class hotel. The drawing-room is as great a contrast to the old time "ladies' cabin," a room ill-lit and unventilated, not much larger than the basement parlour of a suburban cottage ; nevertheless, spacious enough for its company, as it was too dismal to be much frequented.

Charles Dickens' allusion to the cruet-stand will remind old travellers of the monotonous fare of those early days. Nowadays the food supplied to passengers is as varied and as fresh as in a first-class hotel. This improved state of things is chiefly owing to the introduction of refrigerating machinery, by means of which it is possible to keep all kinds of provisions fresh for unlimited periods. Meat, fish and vegetables are thus preserved in the cold storage departments which form an important feature in the equipment of all large ocean liners. The poultry pen no longer is needed, and sweet, if not new, milk is obtained in greater abundance

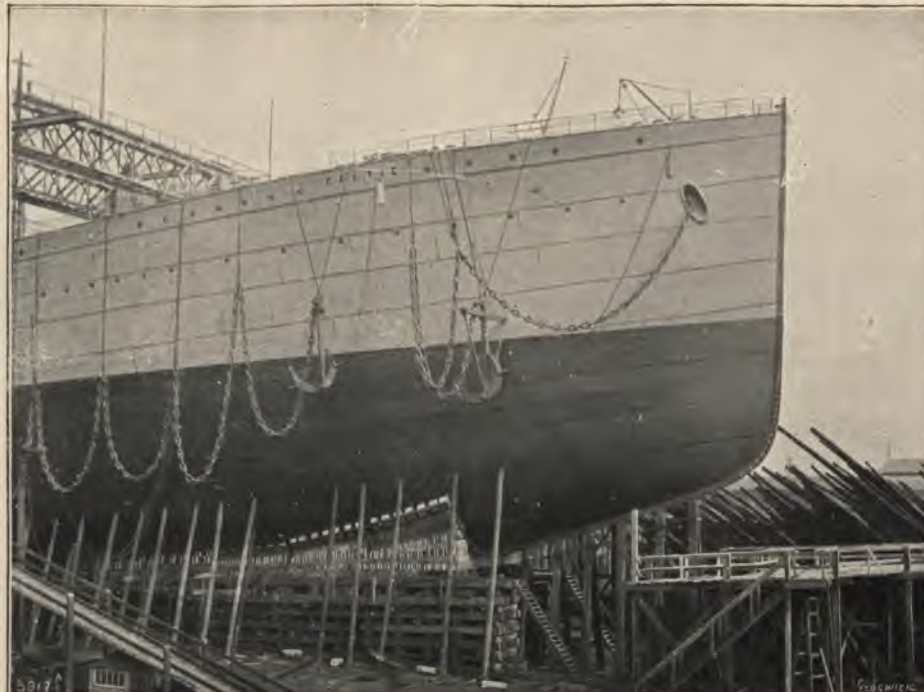


FIG. 41.—Forebody of the *Celtic* on the Stocks.

than when it was necessary to take an unfortunate cow to sea for the purpose of supplying it. The electric light has displaced the old oil lamps, to the immense advantage of the passengers; and electrically driven fans supply fresh air in abundance on all decks; so that the peculiar steamer odour, which characterised even the best managed vessels in old days, is no longer a terror to the sea-sick passengers and an inconvenience to all.

The descriptions of large passenger steamers have been largely confined to liners on the North Atlantic, because the vessels of this route afford the most notable illustrations of advances made in steam navigation on the ocean. It is, of course, the case that other lines besides those mentioned have shown spirit and energy in their respective fields of enterprise; but, as this handbook is a sketch of the progress in ship construction and not a history of shipping companies it is not necessary to describe the many remarkable vessels which ply on other routes. The wealth and number of the passengers carried, the importance of the trade, the stormy nature of the seas crossed and, no less, the close competition that has been experienced, have combined in producing conditions which have led to the largest and swiftest ships being those which run between Liverpool, or Southampton, and New York, and more recently between the latter port and Bremen, or Hamburg.

The Peninsular and Oriental Steamship Company stands beside the Cunard Company as a historic example of the early enterprise of Great Britain in the establishment of ocean steam navigation and, like the sister line of the North Atlantic, is still pursuing a vigorous career. One of the first steamers used by the Peninsular Steam Navigation Company, which was the parent of the present P. & O. Company, was a little paddle boat, the *William Fawcett*, built and engined

in the Mersey, in 1829. She was for some time employed as a ferry boat in that river, and was afterwards employed by the Dublin and London Steam Packet Company in the trade between those two cities. She was 75 ft. long and her engines developed 120 horse-power; her speed in favourable weather was 8 knots. We may compare her with one of the recent steamers of this Company, the *Moldavia*, which is 520 ft. long between perpendiculars, 58 ft. 3 in. wide, and 37¼ ft. deep. She is 9,500 tons gross, the under deck tonnage being 5,300 tons. When fully laden, her draught is over 27 ft. and the displacement about 15,000 tons. She is a twin-screw vessel, and her engines will develop 12,000 horse-power and drive her at 18 knots as a sea speed, the voyage to Adelaide being made in 38 days, including stops. The daily consumption of coal is 180 tons, or about 1·4 lbs. per horse-power per hour. She will carry 3,000 tons of cargo and her bunkers will hold 2,000 tons of coal. Four vessels of this type have been built.

The Orient Steam Navigation Company own vessels about 500 ft. long and 8,300 tons and 10,000 horse-power, the speed being 18 knots. The Pacific Steam Navigation Company have in the *Ortona* a vessel 500 ft. long, of 8,000 tons and 10,000 horse-power, the speed being 18 knots.

A limitation is placed on the design of ships which voyage to the East through the Suez Canal on account of the restriction of draught. What ship designers chiefly desire now is freedom to make deeper hulls, and the great bar to those much longer vessels to which ambitious naval architects look forward in the future is the want of depth in docks and harbours. By dredging channels, or by adopting ports of departure and arrival with deeper waters, something in this direction may be done on the Atlantic route; but, on the short route to the Orient the governing factor is at present the depth of the Suez Canal,

Fig. 42.—The *Baltic.* 1904.

The service to South Africa has recently received some notable additions. The Union-Castle Line have two fine steamers named the *Armadale Castle* and the *Kenilworth Castle*, built by the Fairfield Shipbuilding and Engineering Company, and by Messrs. Harland & Wolff respectively. They are each 570 ft. on the water line, 64 ft. 6 in. wide, and of a moulded depth of 42 ft., the gross tonnage being about 13,000 tons. They have quadruple-expansion engines of 12,500 horse-power, which give a speed of 18 knots. They carry 350 first-class, 200 second-class and 270 third-class passengers.

The *Suevic* is a large steamer designed for the Australian service, but is not intended to pass through the Canal, making her passage by rounding the Cape of Good Hope. She was built in 1901 for the White Star Company. She is 550 ft. long between perpendiculars and 63 ft. wide, and of 12,500 tons. Her engines indicate 5,000 horse-power and her speed is 13 knots, the coal consumption being 80 tons a day. She will carry nearly 12,000 tons of cargo, and has accommodation for 430 passengers. If she were required to sail round the world, sufficient coal could be put on board and, in addition, there would be cargo capacity at the commencement of the journey for 8,000 tons, whilst on the homeward voyage from the Antipodes the return cargo might amount to 11,000 tons. The cost for coal per 1,000 ton mile would be about 3d., and an expenditure of about 3s. would supply coal to transport one ton of cargo from Liverpool to Australia.

Another fine ship employed on the traffic to the East is the *Grosser Kurfürst* of the North German-Lloyd Company. She is said to be the largest merchant ship that has passed through the Suez Canal, being of 13,182 tons register. Her engines are of 9,700 horse-power and her speed is 15 to 15½ knots.

While all this astonishing development was going on in

the great ocean passenger steamers, corresponding improvements were being made in the principal cross-Channel and coasting services.

The mail boats of the City of Dublin Steam Packet Company have been already referred to as the most important of our cross-Channel steamers. (*See* pages 36 to 38.) About the year 1895 it was determined to improve the mail service between Great Britain and Ireland *viâ* Holyhead and Kingstown, both by rail and steamer, and the City of Dublin Company entered into a contract with the Postmaster-General by which they undertook to supply four new and very fast mail steamers to replace the famous paddle boats, already described, which had rendered such excellent service for so many years. Accordingly, four twin screw steamers were built by Messrs. Laird Brothers, and commenced their service in the spring of 1897. In size, speed, and accommodation they are superior to any other vessels engaged round the coasts of the British Isles. They all realised a speed of 24 knots on their trials and they can, in case of necessity, easily accomplish the run between Holyhead and Kingstown in 2¾ hours. They were built and engined by Messrs. Laird, of Birkenhead, and are named, like their predecessors, after the four Provinces of Ireland. The following are their principal data :—

Length between perpendiculars	360 ft.
Breadth, moulded	41 ft. 6 in.
Depth, moulded	29 ft. 3 in.
Draught	13 ft.
Tonnage, gross	2,633 tons.
Tonnage, net	733 ,,
Displacement	2,185 ,,
Type of engines	Triple-expansion with four cylinders.
Diameter of high pressure cylinder	29 in.
,, ,, intermediate cylinder	45 ,,
,, ,, low pressure (two) cylinders	48 ,,
Stroke	33 ,,

Fig. 43.—The *Ulster*. 1897.

Power	.. 9,143 I.H.P.
Type and number of boilers ..	.. Four double-ended Scotch.
Pressure of steam	.. 175 lbs.
Heating surface	.. 18,460 sq. ft.
Grate area	.. 520 sq. ft.

These vessels are, of course, built of steel and are of light, but at the same time, strong construction. They are subdivided by means of twelve watertight bulkheads, ten of which are carried up to the tonnage deck and are also provided with forecastle decks forward. The bunkers can carry 122 tons of coal. Fig. 43 gives a view of one of these vessels.

CHAPTER VI.

ON THE DEVELOPMENT OF TYPE IN IRON AND STEEL MERCHANT STEAMERS.

THE most casual observer must have noticed in our large commercial ports the great variety in the types of iron merchant steamers. While some have flush decks, others are crowded with deck erections, such as bridge-houses, poops of varying dimensions, raised quarter-decks and forecastles. In some types the poop, or the raised quarter-deck and the bridge-house are combined, and even carried forward to a considerable distance towards the forecastle: in others the fore part, or the after portion, of the vessel is covered in by a light turtle-back protection, or shelter deck.

It need hardly be stated that the creation of these various types has not been due to arbitrary motives. On the contrary each type has been developed in furtherance of peculiar trade requirements, modified by considerations relating to the safety of the ship at sea, the tonnage laws, or economy of construction and working. As the growth of these varieties is of comparatively recent origin, it will be possible to give a short account of the reasons which led to the adoption and development of the principal types.

It might naturally be supposed that the simplest form of iron ship would be one provided with a continuous flush deck from end to end, and, in fact, we find that this was the type first adopted. Unless, however, such a vessel had a very considerable free board, or height

from the load-line to the deck level, it would be exposed in navigation in rough weather to the danger of being swept from end to end by seas coming over the bow, or, in the case of following seas, of being pooped. At the forward end of the vessel the conditions affecting the working of the anchors render it desirable that the gear should be placed on a raised structure, quite independently of the advantages which such a structure gives in preventing the vessel from being swept by waves. Moreover, as the hand steering wheel is situated close to the stern, it is vitally necessary that this gear, on which the safety of the vessel may depend, should receive some sort of protection, either by being raised to a sufficient height above the sea-level, or by being partially covered in. Here, then, we have the elements of two deck erections—viz., the monkey forecastle and the short poop erected above the main deck, not to be confounded with the raised quarter-deck (the uses of which will be explained later on).

It is said that these erections were first added to some small flush-decked colliers which were sent out to the Black Sea freighted with materials during the Crimean war. Before being thus fitted some of the hands had been severely injured at the wheel during rough weather. The beneficial effect produced by the additions was very marked.

The origin of the bridge-house was, of course, the look-out bridge, fitted amidships, over the deck-house, for the use of the navigating officers and look-out. At first it was a very light erection, forming no essential portion of the ship's structure ; it eventually, however, became a feature of great utility, and was made an integral portion of the ship, of primary importance in protecting the engine hatchway from the incursions of the sea.

In Figs. 44 to 52 will be seen sketches of the principal types of iron and steel ships registered at Lloyd's.

Fig. 44 is a flush-decked vessel, with central engine and boiler casings.

Fig. 45 is a vessel with a monkey forecastle, a bridge-house over the engine space, with two passages through it, and a short poop, or hood, for the protection of the steering gear.

Fig. 46 is a vessel with a top-gallant forecastle, a bridge-house enclosed at the end with an iron bulkhead, and a longer poop.

Fig. 47 is a vessel with a top-gallant forecastle, a bridge-house, and a short raised quarter-deck. The difference between

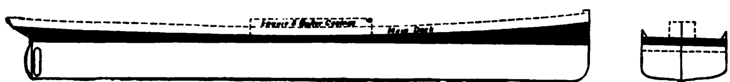


FIG. 44.

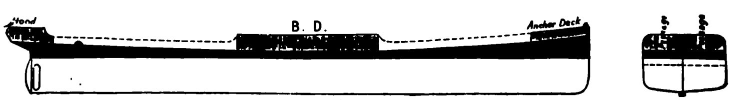


FIG. 45.

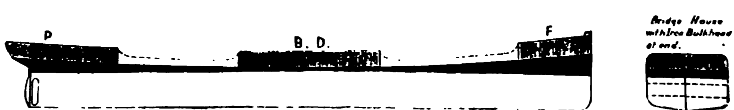


FIG. 46.

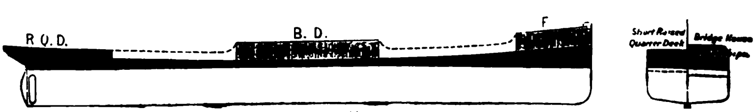


FIG. 47.

a poop and a raised quarter-deck is that the former is a structure raised over a deck ; whereas the latter has, in the case of single-decked vessels, no deck under it, and is formed, in fact, by raising, or stepping, a certain portion of the deck of the vessel. The raised quarter-deck variety is a most important type of vessel, which played a very large part in the carrying trade of the country, and its qualities have formed the subject of much controversy. Its genesis and development will be fully discussed hereafter.

Fig. 48 shows a vessel having a top-gallant forecastle, with a long poop and bridge-house combined, known as one type of

FIG. 48.

well-decker, the well being the open break between the forecastle and the bridge-house. The well, which is not required for the purpose of carrying cargo, is left open, for two reasons : firstly, because if covered in, the space enclosed, while quite useless, owing to considerations affecting the trim of the vessel, for carrying the general class of cargo, would be included in the tonnage measurement of the ship, on which dues would be payable, and hence the annual cost of working would be increased; secondly, in the case of the vessel being swept by waves coming over the bow, or forepart of the vessel, if the well were covered in the waves might sweep right along the superstructure from stem to stern; whereas, when the well is open, the water finds its way into it, and speedily passes overboard by the freeing scuppers, while the after portion of the vessel is left dry.

Fig. 49 is a vessel having a top-gallant forecastle, a long raised quarter-deck and bridge-house combined. This type of

FIG. 49.

vessel is also known as a well-decker, but differs from Fig. 48 in having a raised quarter-deck instead of a poop.

Fig. 50 shows a "shade-decked" vessel, having a continuous

FIG. 50.

upper-deck, but of lighter construction than the rest of the vessel, and with openings in the sides.

Fig. 51 represents an "awning-decked" vessel. This type

FIG. 51.

has a continuous upper-deck of lighter construction than the rest of the vessel, and with sides completely enclosed above the main-deck.

In Fig. 52 we have a "spar-decked" vessel. The difference

FIG. 52.

between this and the last type is, that the scantlings above the main-deck are heavier than in an awning-decked vessel, but not so heavy as in a three-decked vessel. The three last types are similar in external appearance.

The above constitute the older types of vessels classified in Lloyd's Registry. In each case the space between the load-water line and the principal deck is coloured black, while the various deck structures are shaded. In comparatively recent times several new types, such as Turret Ships, Trunk Deckers, Cantilever framed vessels and ships with side ballast tanks, have been introduced and are classified at Lloyd's. These types are described later on.

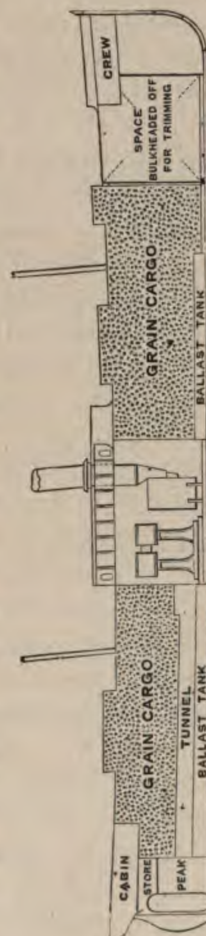


FIG. 53.

We may now proceed to consider the reasons which have called these various types into existence. The development of the class having a monkey forecastle, a bridge-house, and short hood over the steering gear has been already explained. By degrees the forecastle was developed in height to about 6 ft., and was used for housing the crew. A full poop of the same height was added aft for the officers and passengers. The engine and boiler openings were originally protected only by glazed skylights and low coamings. The loss of the *London* in the winter of the year 1865-66—due to the carrying away of her engine skylight in

a gale—led to the better protection of this most vulnerable opening by means of an iron casing, about 6 ft. high, which was afterwards developed into an important feature by being enlarged to the sides of the vessel, and thus formed the bridge-house.

About the year 1865 a type of vessel was brought out on the north-east coast, which was intended to overcome some practical inconveniences of flush-decked steamers, that were found to arise when these vessels were used for the general carrying trade of the world.

Fig. 53 represents in sketch a longitudinal section of a flush-decked vessel. It will be readily seen that, in the after-hold a considerable amount of space is taken up by the screw-tunnel, and the volume of the after-hold available for stowage of cargo is less than that of the fore-hold. The necessity of fining the lines of the after body in order to permit a free run of water to the propeller, made it practically impossible to improve on this state of things by any alteration in the shape of the hull. So long as the vessel was employed in carrying dead-weight cargo, which could not in any case nearly fill either hold, no practical inconvenience was found to result. When, however, homogeneous cargoes were carried, such as grain, which completely filled the holds, the vessel was found to trim by the head. In the case of very light cargoes the difficulty could be got over by filling the water-ballast tank aft, as shown in Fig. 54, but this of course meant carrying a considerable amount of dead weight on which no freight was earned. At one time an attempt was made to increase the cubic capacity of the after-hold by moving the engines and boilers further forward. This was found to answer when the vessel was loaded; but when in ballast, she would again trim by the head, and the propeller would become very lightly immersed,

causing great inconvenience when moving from port to port. Larger vessels of this type were built with two decks. The second deck added strength to the structure, and was very convenient in loading general cargo. When, however, the cargo was homogeneous, consisting, for instance, of grain or pulse, settling took place under the decks when the loading was hurriedly or carelessly carried out, with the result that, in bad weather the cargo often shifted, and could not be got at to be retrimmed. The vessel then acquired a permanent list, and many cases of ships reported "missing" have, no doubt, foundered, with all hands, from this cause.

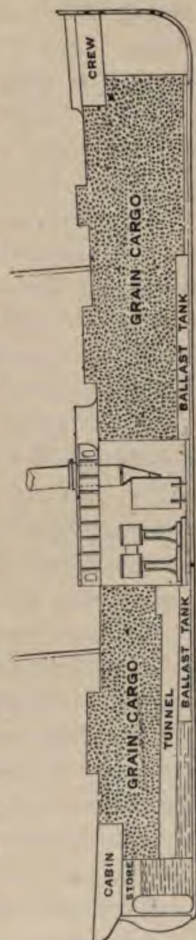


FIG. 54

Another method of overcoming the difficulty due to the relatively small capacity of the after-hold was by constructing a long full poop as shown in Fig. 48. The poop, however, is only useful for very light cargo, while tonnage dues have to be paid on the whole cubical contents available for stowage.

The north-east coast shipowners solved the difficulty by increasing the volume of the after-hold by the simple expedient of raising the part of the deck which covered this portion of the hold, till the cubic contents of the two holds became approximately equal. A vessel of this type is shown in sketch longitudinal section, in Fig. 55, in which it will be

noticed the deck is raised at the after-side of the engine-room bulkhead. Owing to the equality of contents of the two holds, such a vessel will float on an even keel when loaded, and when in ballast will not trim by the head. There are no unutilisable spaces to pay tonnage dues on. Owing to there being no " 'tween-deck " spaces, little trouble is experienced from shifting of grain cargo; but, should it take place, the surface of the cargo is easily got at for purposes of trimming. The stability of this type of vessel when laden with homogeneous cargo is all that can be desired. The advantages of the " well " between the forecastle and the bridge-house have already been explained.

The raised quarter-deck, "well-decked," type of steamer for a time superseded all others on the north-east coast. It is also used in the Atlantic cargo trade, but when thus employed the deck erections are made stronger in scantling, and the vertical faces of these erections, liable to receive the shocks of heavy seas, are stiffened with numerous angle irons and web plates; also the alley-ways through the bridge-house are done away with, and this structure is entirely closed in.

In order to meet the case of having to carry very heavy dead-weight cargoes, such as ore, or railway iron, special features had from time to time to be introduced into the construction. If these cargoes

FIG. 55.

could be distributed evenly over the bottoms of the holds no difficulties would arise as far as the structure is concerned. With heavy weights stowed in such a position, however, the centre of gravity of the cargo would be too low, and the vessel would be liable to roll with excessive violence in a seaway. In order to raise the centre of gravity, the cargo had to be piled up, and this could only be done by concentrating it in certain portions of the vessel, and the forward compartment of the fore-hold and the after-portion of the after-hold were left empty when the vessel was loaded amidships, as shown in Fig. 55. Under such conditions a vessel is liable to sag like an over-loaded girder, especially when its ends are supported by waves, and heavy longitudinal stresses are then brought to bear on the top sides and bilges. See Appendix I.

Some vessels of this type are of very considerable size. The largest yet built is the *Anubis*, 382 ft. long and of 4,763 gross tons. The *Roland* is 345 ft. long, of 3,603 gross tons, and can carry a dead weight cargo of 5,400 tons. There are several in existence whose dead weight capacity exceeds 4,000 tons. As built on the north-east coast, these large, raised quarter-deck vessels have some structural features worthy of mention. It is a task of no mean difficulty to build single-deck vessels of the above sizes, carrying enormous dead-weight cargoes, often concentrated about the middle of the ship, and, consequently, inducing very heavy longitudinal stresses. Accordingly we find that the longitudinal strength of these ships has received special attention. Cellular double bottoms have been introduced, and also iron-plated decks. In the shell-plating extra long plates have been made use of in order to diminish the number of butt-joints, while the upper strakes of the plating are made of increased scantling. When used for carrying grain, the

large vessels are fitted with vertical fore-and-aft wooden divisions in the hold, extending from the transverse bulkheads to the hatches. Their use is to diminish the effect of the shifting of the cargo by dividing it equally over the two halves of the ship. In the vessels under consideration, these fore-and-aft divisions are sometimes made of iron, well stiffened with angles, and afford considerable local support, though of course they have not the same value as if they were continuous. The engine-room space has been strengthened by the introduction of large through beams, well supported by stanchions, and the sides of the bunkers, which run fore and aft vertically, have been so strengthened as to become structural features of the vessel, instead of being, as formerly, merely intended to keep the fuel in place. The bridge and quarter-deck side-plating has been made of the same scantlings as the shell-plating of the hull, and has been backed up by frame-bars, rolled in solid *Z* section, in place of the riveted frame and reverse bars generally used; moreover, these frames are carried up to the top of the structure, instead of stopping short at the main-deck stringer, as is usually the case in cargo boats. The weak point in the structure of these vessels, especially when they are of large size, is the want of continuity of the deck caused by the raising of the portion over the after-hold.

Another feature of these vessels, and of many other raised quarter-deck vessels built subsequently to the year 1885, is the prolongation of the bridge-house forward, so as greatly to contract the well-space and to form a "'tween-deck" space forward of the engine-room. This feature was adopted in consequence of the hostile attitude assumed by the Board of Trade towards the earlier type of "well-deckers" before their excellent sea-going qualities were generally recognised. The Board of Trade for a time insisted that these vessels

should be sailed with an amount of free-board which meant pecuniary loss to the owners; but, it having been ascertained that a more favourable free-board would be granted, provided the "well" space were curtailed, many boats of this type were built with the bridge-house extended in the manner illustrated in Fig. 56. The disadvantage of the extended bridge-house is similar to that pertaining to the full poop, viz., the cubical space enclosed is so great that it can only be utilised to advantage for carrying light goods, while the increased tonnage dues, which are levied on the whole enclosed volume, are heavy relatively to the increased earning power. In fact, the extended bridge-house type of "well-decker" is built in violation of the natural causes which led to the adoption of the old raised quarter-deck type, and owes its existence chiefly to legislative, *i.e.*, artificial causes.

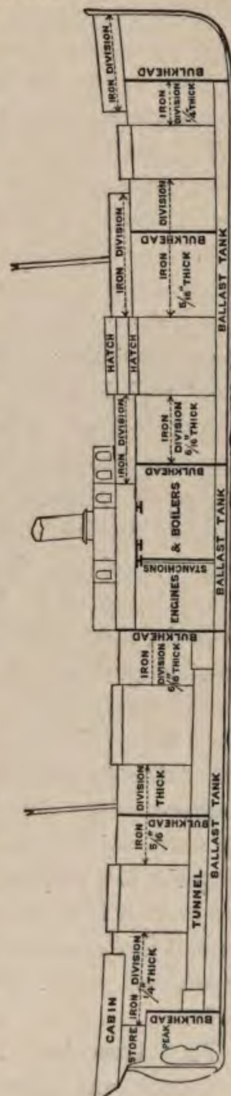


FIG. 56.

It may here be mentioned that the action of the Board of Trade towards the old raised "quarter-deck" type was one of the principal causes which led to the appointment of the Load-line Committee. The report of that committee led to legislation, which imposed upon the Committee of

Lloyd's Registry for British and Foreign Shipping the duty of fixing load-lines for vessels, and the raised quarter-deck type were allowed to sail with their old free-boards, subject to the front of the bridge-house being so strengthened as to be undeniably capable of resisting the impact of heavy seas.

The great popularity which this type of vessel enjoyed for some years may best be illustrated by figures showing the proportion which it bore to some other descriptions of cargo boats in the years 1875 and 1890. In the former year, out of the total tonnage of cargo boats built, the "well-deckers" counted for 30 per cent. and the three-decker type for 31 per cent. In 1890, however, the "well-deckers" amounted to 42·9 per cent., and the "three-decker" to only 18 per cent. The popularity of the type was accounted for by various reasons, chief among which appear to be that they were single-deck vessels, and of small register tonnage, and therefore cheap in cost of production and in working. They were also of such proportions that while they could be fairly filled with homogeneous cargo, such as grain, they could also carry dead-weight cargo in the best possible position relatively to the centre of gravity. They had a high range of stability, great safety at sea, and were easy to keep in trim, either when loaded or in ballast, while the existence of the well, besides reducing the registered tonnage, saves the deck aft of the well from being swept by seas, which would otherwise often cause great injury and frequent loss of deck fittings and boats. With all these advantages it is no matter for surprise that they came into such extended use; but they have now been superseded by other types, and at the present time (1906) very few of them are built.

The "three-decked" vessel, of which type the shade-deck, spar-deck and awning-deck classes are variations, differed

materially from the type with full forecastle, full poop, and bridge-house; for, whereas the latter were generally about 17 ft. 6 in. deep below the deck on which the upper erections were constructed, the former were much deeper, viz., about 24 ft., the scantlings being maintained at their full strength for the whole of this depth, and another deck was laid, the forecastle, bridge-house and poop remaining as in the other type. It should be added that, though the depth was increased, the breadth and length remained unchanged. Hence these early "three-decked" vessels were relatively deep and narrow. This probably was due to the fact that increased breadth was formerly erroneously considered to be the principal element in the resistance of vessels to propulsion. These steamers were, from their great strength, well adapted to the carrying of dead-weight, but when loaded with homogeneous cargoes to the depth of immersion, usual with dead-weight, they proved to be unstable, and many vessels of this type were, in consequence, lost at sea. Attention was called to this subject by the late Mr. B. Martell, then Chief Surveyor of Lloyd's Register, in a paper "On the Unseaworthiness of Merchant Vessels," read before the Institution of Naval Architects in the year 1880. It was afterwards shown by Mr. Martell that, between the years 1875 to 1885, there were on the average 450 vessels of the narrow "three-deck type" afloat, and during this period no less than 75, or 16·6 per cent. of the total, were reported as lost at sea. During the same period the number of "well-deckers" rose from 430 in 1875 to 1,400 in 1885 on the British Register, and only forty-nine of these, or one-third of the former percentage, were reported as foundered or missing.

In consequence of the revelations made in this paper, the breadth of the "three-deck" type was gradually increased, so that, while in 1879 the average breadth of a vessel of

24 ft. depth of hold was 34 ft., it had been increased in 1890 to 38·9 ft., with the satisfactory result that the change in proportions was accompanied by a very marked diminution in the number of losses.

The "spar-deck" type was a modification of the "three-decker," intended to meet the case of carrying passengers in the "'tween-decks." It was considered that in such cases the scantlings, generally, might be somewhat lightened, especially in the upper works. In the earlier examples of this type, not only was the plating lighter, but only half of the frames were carried up to the spar deck. These vessels were originally intended to be restricted to the carrying of passengers in the "'tween decks," but this restriction was found to be such a disadvantage that owners took to building a somewhat stronger class of boat, but still not so strong as the true "three-decker." In the improved type all the frames were carried up to the spar deck, and the plating of the upper works was somewhat increased. In other respects there was no difference between the "three-deck" and the "spar-deck" types.

In consideration of the relative lightness of their upper works, "spar-deck" vessels had to go to sea with a somewhat greater free-board than "three-deckers," a circumstance which accounts for their great freedom from loss. On the average, only one vessel per annum of this type was lost at sea out of a total of about 500.

The "awning-deck" class originally arose to meet the necessities of the native Eastern passenger traffic, and was designed in order to provide a light permanent shelter from the sun for the hordes of pilgrims and coolies which have often to be transported in tropical waters. Up to the main deck the scantlings and structural arrangements were identical with *those* of the "spar-deck" class. The deck erections, however,

Fig. 57.—The *Turret*. 1892.

were much lighter, and large openings were made in the vessel's sides for the purpose of ventilation. The same process of development took place in this type as in the "spar-deck" class. By degrees, owners began to carry cargo as well as passengers in the space covered by the awning deck, and it became necessary to strengthen the structure above the main deck by continuing all the frames upwards; the plating, beams and deck, however, were lighter than in the "spar-deck" class. The side openings also were closed. All "awning-deck" vessels classed in Lloyd's Register had, in consequence of the lightness of their upper works, a special load-line fixed for them, which is marked on their sides, and recorded in the Registry Book.

The "shade" or "shelter-deck" class took the place of the original unstrengthened "awning-decker." It was the lightest built vessel of the "three-deck" type. It was provided with side openings for ventilation, and had a fixed load-line assigned to it. The latter type of vessel was referred to by Mr. E. W. De Russett in a paper read before the Institution of Civil Engineers in April, 1904, as "still in favour for the largest class of cargo and intermediate steamers, owing to the superior sea-worthiness arising from large surplus buoyancy, and also on account of covered-in shelters and relatively small registered tonnage."

During the last twelve years an altogether novel type of single-deck vessel called the "Turret" steamer has been introduced and developed by Messrs. William Doxford & Sons, of Sunderland. The first vessel of this class, the *Turret*, gave her name to the type and was built in 1892. Since then a large number of turret steamers have been built by Messrs. Doxford.

In Fig. 57 is given a view of the *Turret*, and Fig. 58 shows her construction and the novelty of the form of her cross section. It will be seen that the side of the vessel

at the gunwale is curved in until it falls into a horizontal portion which forms the side deck, generally known as the "harbour" deck; the plating then sweeps up to form the side of the so-called "turret." This structure and the harbour decks extend from end to end of the vessels, and, being continuous, there is no need for the additional strengthening necessary in some types of ordinary cargo steamers at the breaks of decks.

The deck of the turret structure, called the "turret" deck, forms a navigating platform between 10 and 11 feet above the water, and on it all openings, such as hatches and ventilators, and also the usual deck fittings, are placed. The turret not only provides a convenient navigating platform, it also forms an excellent feeder in case of subsidence, when homogeneous cargoes such as grain, or coal, are carried; thus shifting of the cargo in the main body of the ship is prevented. Any shifting that may take place in the turret itself is of little importance. The curved base of the turret and the curved gunwale facilitate the stowage of such cargoes. The depth of the turret can be increased aft so as to provide additional space in the after-hold and thus enable the vessel to trim by the stern for the reasons given when the genesis of the raised quarter deck, or well-decked, type of steamer was explained (*see* pp. 108 to 110). The sides of the turret provide two continuous girders running from end to end of the ship, along the top of the harbour deck, to which they impart great stiffness, thus rendering the use of the usual number of pillars for supporting the deck unnecessary, a circumstance which is very advantageous for stowage purposes, and permits of the use of long hatchways. The turret sides also increase the structural depth of the ship, and thus augment the strength of the latter in resisting longitudinal bending stresses,* while

* For an explanation of this statement see Appendix I.

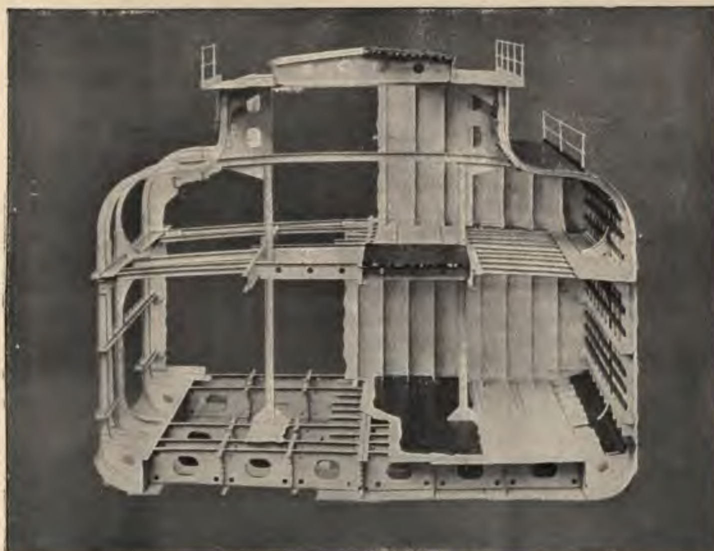


Fig. 58.—Structural arrangements of the s.s. *Turret*.

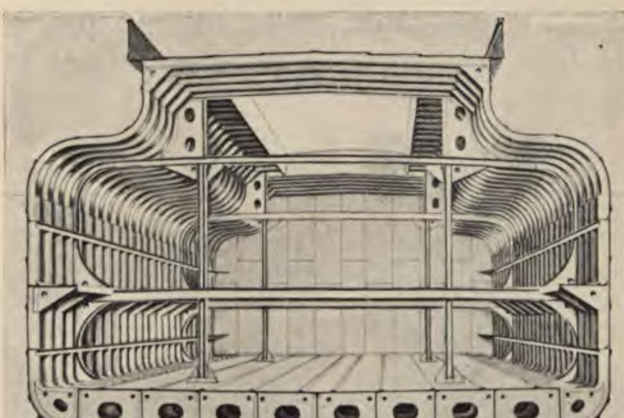


Fig. 59.—Cross section of a modern steamer of "Turret" type.

the peculiar form of the cross section, with its curved gunwale and curved turret base, is well adapted to resisting transverse stresses. As every part of the structure contributes to the strength, and as there are no breaks in the continuity of decks, there is considerable saving in the weight of ships of this type as compared with ordinary types of cargo boats of the same dimensions, and thus relatively great dead-weight cargoes can be carried.

Another advantage claimed for the turret structure is that it effectually prevents the seas from breaking right over the ship. It is stated that the navigating platform is always free from water, except in the condition of spray.

The form of cross section is not the only peculiarity of this type of vessel. There is also a total absence of "sheer," by which term is meant the rise of deck in the fore-and-aft directions which is usual in sea-going vessels. In other words, the decks are parallel to the water line. The high turret structure enables the sheer to be dispensed with, while the necessary reserve buoyancy is retained, the construction is simplified and the net registered tonnage reduced to a minimum. To compensate for the absence of sheer at the bow these vessels are provided with a top-gallant-forecastle. As dues are paid on the registered tonnage, the working costs are reduced, while, as has been already pointed out, the earning power, when dead-weight cargoes are carried, is increased; hence, from the commercial point of view, when engaged in dead-weight trades these vessels are satisfactory. Experience has proved that they are also excellent sea-boats and they are further very convenient for loading and carrying homogeneous bulk cargoes. The harbour decks have been found to be quite suitable for carrying deck loads of timber, or long iron girders, even in very bad weather. Vessels of this sort are also built to carry the lightest kinds

of so-called "case" cargo successfully; for instance, in those built for the Nautilus Company, the allowance of cargo stowage capacity is no less than 70 cubic feet to the ton of weight. For the Clan Line turret steamers of 8,000 tons have been built, with 'tween decks for the carriage of general cargo.

Fig. 59 represents the midship section of a modern turret steamer, and Fig. 60 the midship section of a special type with holds clear of pillars and beams so as to ensure convenient stowage.

A sectional model of a turret steamer is in the collection at the Victoria and Albert Museum, and shows the constructional details very clearly.

The machinery in the turret type is sometimes carried right aft. The position has some advantages; for, when the ship is without cargo it helps her to trim by the stern, and thus gives good immersion to the propeller; the long unbroken space of the hold also greatly facilitates the stowage of cargo; moreover, the usual long shaft tunnel is avoided.

Since these vessels were first introduced they have increased in size until, in 1903, the *Grängesberg* was said to be the largest single-decker in existence. This remarkable vessel is 440 ft. long, 62 ft. wide, and 29 ft. depth of hold and will carry 10,000 tons of ore on a draught of 22 ft. 6 in. There are twelve large hatchways and fourteen derrick posts, placed side by side in two rows along the vessel, with twenty-four derricks; these are worked by twelve double-ended winches. These exceptional appliances for handling material enabled her to discharge a full cargo of ore in twenty-seven hours by means of her own gear. Her engines develop 2,200 horse-power, and her speed is 10½ knots. The one hundredth turret ship was launched from Messrs. Doxford's yard on the Wear in June, 1904. The turret steamer has grown in popularity to such an

extent that in the year 1905 the whole of the very large tonnage (over 85,000 tons) launched by Messrs. Doxford at their yard at Sunderland belonged to this class of vessel.

The "Trunk-deck" type of steamer is very similar to the turret class and presents the same advantages. Vessels of this description have been largely built by Messrs. Ropner, of Hartlepool. The so-called trunk is a structure which closely resembles the turret, but the gunwale of the ship, and the bases of the turret, are not curved as in Messrs. Doxford's steamers. The gunwale resembles that of any ordinary ship and the girders which form the sides of the trunk rise from the main deck nearly at right angles.

The peculiar circumstances of the trade between the United Kingdom and the United States of America have caused some considerable changes in the provision of space for water ballast. Owing to the operation of the McKinley tariff the goods and produce that are exchanged for our imports from the United States are not sent from British ports, and the consequence is that our cargo steamers on the outward voyages cross the Atlantic in ballast. The ordinary provision for water ballast in the double bottom and peak tanks is not sufficient for the Atlantic trade, especially in winter, and many accidents have occurred through the breaking of screw shafts, owing to the propellers not having been sufficiently immersed and having consequently raced in stormy weather. Injury to the forward part of the bottoms of steamers has also frequently resulted.

Many methods for providing additional tank space have been devised. If the whole of the weight of the extra ballast were concentrated in the lower part of the ship, violent rolling would result; hence it became necessary to contrive means for raising the tanks intended to hold the additional quantity. Two methods deserve special mention. The

first is called after the name of the inventor, Mr. McGlashan. It consists in providing double sides as well as a double bottom, over about three-fifths of the vessel's length amidships. The arrangement somewhat resembles that adopted in the *Great Eastern* (*see* page 150). The double sides are carried right up to the upper deck. The side and bilge stringers are attached to both inner and outer shells, and form a series of intercostal longitudinal girders similar to those in the double bottom. Of course this arrangement adds considerably to the strength of the ship. It provides for the reception of a large amount of additional water ballast at a suitable height, and is said not to add materially to the weight of the hull.

The second system is Harroway and Dixon's patent cantilever framed steamers, fitted with high wing ballast tanks in addition to the ordinary tanks in the double bottom. These vessels are built by Sir Raylton Dixon & Company, Limited, of Middlesbrough-on-Tees, and are specially suited for the coal, ore, grain and timber trades. Fig. 61 shows a cross section of a single decker of this type. It will be seen that the transverse frames are bent inwards on a straight slope terminating at the coamings of the hatches and are plated over. Frames are also carried vertically upwards as in an ordinary ship, to the level of the deck, and the triangular spaces beneath the deck and bounded by the vertical and sloped sides constitute the raised wing tanks. In this manner an addition of 75 per cent. of water ballast over that contained in the double bottom and in the peak tanks can be carried at the right height to give easy motion in a seaway. The wing tanks run right fore and aft on each side of the ship, and constitute two box girders which greatly increase the strength both longitudinally and transversely; so much so, in fact, that all pillars, beams, and web frames can be dispensed with in the holds, and the latter

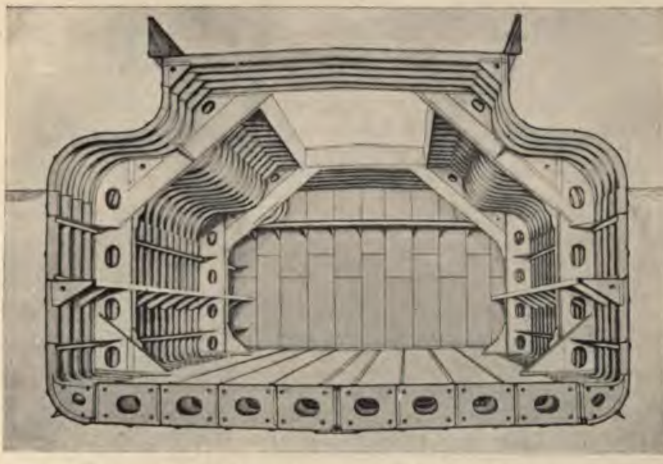


Fig. 60.—Cross section of a modern steamer of "Turret" type, constructed without beams or stanchions.

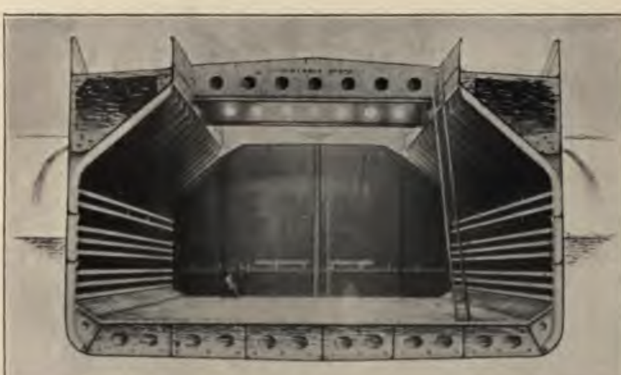


Fig. 61.—Cross section of cantilever framed steamer. Harroway and Dixon's patent.

are perfectly clear for stowage. The sloping sides of the tanks make these vessels perfect self-trimmers for coal or grain cargoes. An incidental advantage is that very wide and long hatchways can be provided. The ballast tanks are not measured into the tonnage, and vessels can be built of this type so as to carry three tons of dead weight to each ton of net register. They can also be built with 'tween decks, and the engines and boilers may be carried either amidships or aft.

The above constitute the various types of vessels for general trade which have found their way into our mercantile marine, and which have been accepted as successful cargo carriers. From time to time new arrangements are tried to meet special cases, but it is not necessary to refer to these in detail as the innovations have not met with general acceptance, and cannot consequently be recognised as types.

Some mention must, however, be made of a class of vessel which has come into use during recent years for the purposes of one special trade only, viz., the carrying of petroleum in bulk. Formerly mineral oils were carried exclusively in barrels holding each about 42 imperial gallons. Three and a half of these barrels would occupy about 50 cubic feet of hold space, while a ton's weight of them would require 80 cubic feet, and as a ton of the usual weight of cargo required to bring a modern three-deck steamer to her load draught does not occupy more than 50 cubic feet of space, it is obvious that this class of vessel is ill-adapted to carrying petroleum in casks. Stated in another way, a steamer that would carry a given weight of cargo running 50 cubic feet to the ton, would only carry 62·5 per cent. of that weight in petroleum in casks, and the petroleum itself would only be a very little more than 50 per cent. of the original weight that the vessel was designed to carry. It

may here be mentioned that, on the average, petroleum runs about 45 cubic feet to the ton, and therefore, with proper arrangements for transporting it in bulk, no difficulty should arise in carrying full cargoes. In carrying in bulk, however, special allowance must be made for large trunks and other fittings which are not required when the oil is loaded in barrels; therefore, under no circumstances, could the whole of the above difference of 50 per cent. be recovered.

In addition to the advantage of being able to carry a much larger cargo in a given vessel, the system of carrying in bulk permits of a more rapid rate of loading and discharging than the old method. For example, a steamer carrying 1,700 tons of petroleum in bulk can be loaded, or discharged, in six hours; whereas, if loaded in barrels, the same operation would occupy four or five days, as there would be about 10,000 casks to handle. This facility for loading and discharging virtually amounts to a considerable increase in the carrying capacity of the steamer over a given time.

In the design of a petroleum steamer several points of the utmost importance have to be attended to. One difficulty that arises is due to the fact that petroleum varies considerably in bulk as the temperature changes. It may be stated approximately that an increase, or decrease, of 20° Fahrenheit causes an alteration in the volume of a given weight of the oil of one per cent. Hence if the oil were loaded full into hermetically closed tanks, and during the voyage the temperature were to rise, the tanks would either stretch or burst; and it must be borne in mind that variations of temperature of from 40° to 60° Fahrenheit are quite common in ordinary voyages, while in proceeding from temperate to tropical seas much greater variations will occur.

A drop of temperature below the point at which the oil was

loaded would result in the contraction of its volume, and the tank would no longer be full. This state of things would be aggravated by any leakage that might take place, and the result would be that in rough weather the liquid would rush violently from side to side of the tank as the vessel rolled, and might do considerable damage.

The foregoing considerations show that it is absolutely necessary to provide some means of feeding the tanks so as to keep them always full. They also point to the desirability, in cases where the tanks are carried right out to the skin of the vessel, of having a middle-line longitudinal oil-tight bulkhead in the tanks, in order to diminish the free surface of the liquid and to reduce the weight of oil which could be displaced to either side when the vessel rolled. Accordingly we find this middle-line longitudinal bulkhead universally adopted in modern petroleum steamers.

The method adopted to keep the tanks full under the influence of change of temperature is to construct a large vertical trunk, rising out of the crown of each tank, and in free communication with the interior. The tank is filled till the liquid rises in the trunk to the height which experience has shown to be desirable and then, if the temperature rises or falls, the only effect produced is that the level of the oil rises or falls in the trunk, the main body of the tank always remaining filled, unless serious loss takes place by leakage, to provide against which contingency arrangements are contrived for collecting the leaking oil and pumping it back again into the tanks.

Another point which requires special attention in this class of steamer is the prevention of the leakage of the oil into the boiler-room, where its presence would certainly give rise to dangerous fire. In order to diminish the chance of leakage into this space, the engines and boilers may be removed from their usual position amidships and placed abaft the oil tanks.

Leakage could thus only take place from one side, instead of from two. Two transverse watertight bulkheads are usually fitted on to two adjacent frames between the fore end of the boiler-room and the tanks, and the space between them is either filled with water, or else pumping arrangements are contrived for discharging any oil which may accumulate in it.

Fig. 62 illustrates two vessels of this type, one with the machinery amidships, and the other with the engines and boilers aft.

Several disastrous explosions have occurred on board petroleum steamers through the ignition of the gases which are given off by the *crude* oil at all temperatures. These gases are of high specific gravity, being from three to three and a half times heavier than air, and hence have a tendency to accumulate at the bottom of tanks after the latter have been pumped out. This points to the necessity of employing air pumps or ventilating fans, in order to clear the tanks and other spaces in the hold from these dangerous vapours.

In some of the earliest steamers for this trade the tanks were separate structures made within the hull of the ship. This arrangement was very satisfactory from the point of view of the security of the cargo, but it greatly diminished the weight of oil that could be carried, and added largely to the first cost of the vessels. In modern practice, the sides of the ship and the deck form integral portions of the tanks; the transverse bulkheads also form two of the sides of each tank.

The special duties to be performed by this class of vessel, and the fact that the engines and boilers are generally carried aft, have caused the introduction of some variations in the deck structures as compared with those of general cargo steamers. For instance, the deck-house amidships, with sides formed by the continuation of the plating of the vessel, which is so necessary

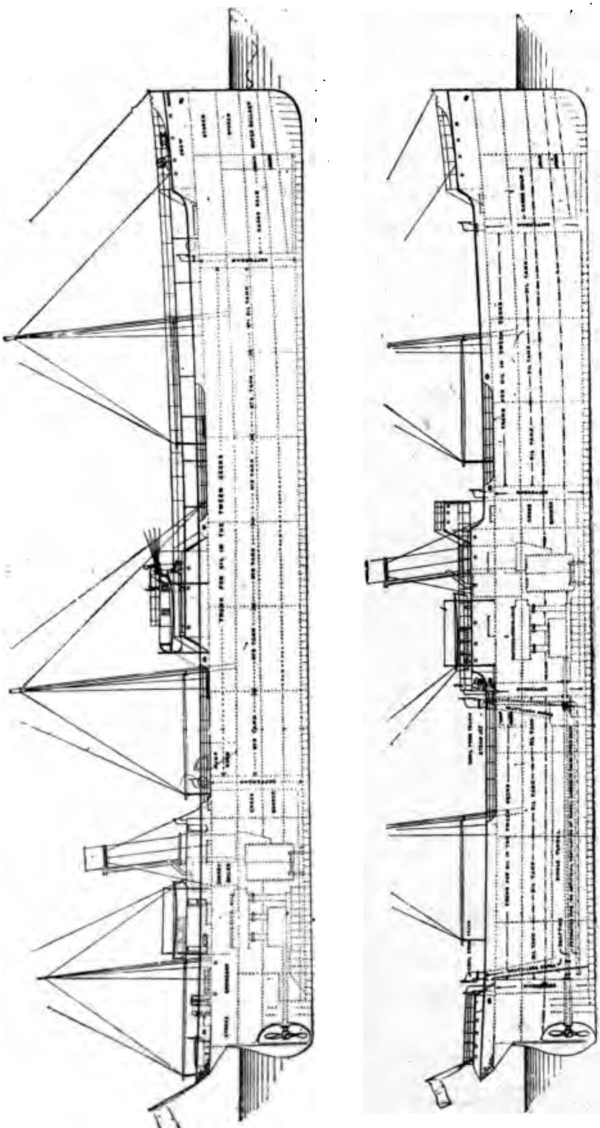


FIG. 62.—Steamers for carrying oil in bulk.

for the protection of the engine and boiler-room openings, disappears, and is replaced by a small deck-house, not extending to the vessel's sides, and used only for navigating purposes. The protection for the engine and boiler spaces and stoke-hold, as well as the accommodation for the officers, is obtained by means of a long poop, all the coamings on the deck of which are made unusually high, in order to prevent the

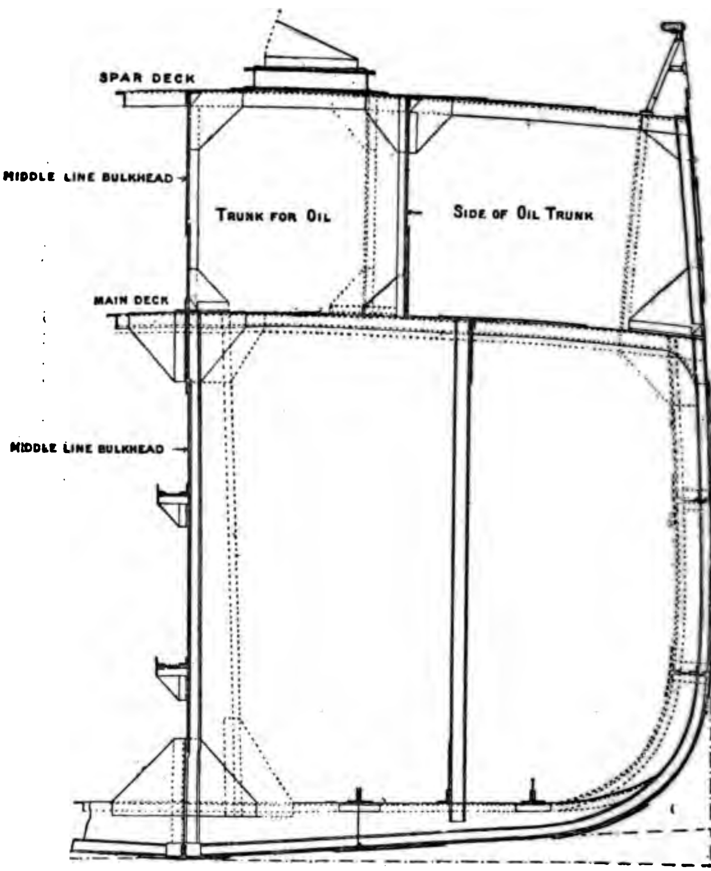


FIG. 63.—Midship section of steamer for carrying oil in bulk.

water from finding its way below. Experience has shown that, for the Atlantic trade it is desirable, in the interests of safety and comfort, to extend the poop as far forward as the deck-house. The crew is accommodated in, and the anchors worked from, a top-gallant forecastle.

It may be pointed out that while the transverse strength of these steamers is very large, owing to the number of athwartship bulkheads, the fact that these bulkheads are built water-tight, makes it necessary that the longitudinal connections be discontinued at each of them, instead of being worked as continuous structures fore and aft. The break in the longitudinal strength thus caused has to be made good by attaching all longitudinals, such as stringers, keelsons, etc., to the bulkheads by strong brackets securely riveted as shown in Fig. 63. The failure to carry out this precaution caused trouble in some of the earlier steamers. It need hardly be mentioned that, with such a penetrating material as petroleum for cargo, the riveting of all watertight work has to be carried out as carefully as the riveting of boilers.

Fig. 63, is a midship section of an oil steamer 260 feet long between perpendiculars, 36 feet beam, and depth to spar-deck 25·5 feet. It illustrates the points to which reference has been made.

In the year 1902 there were nearly 200 oil-carrying steamers on Lloyd's Register. The largest steamer of this class at the time of her launch in June, 1903, was the *Narragansett*, built by Messrs. Scott of Greenock. She is of the shelter-deck type, her length being 512 feet, her breadth 63½ feet and her depth 42 feet. Her displacement loaded is about 21,000 tons, and her dead-weight capacity about 12,500 tons, of which 11,000 tons are oil, carried in sixteen separate tanks. The twin screw engines develop 5,500 horse-power and the maximum speed is 14 knots.

Another class of steamers that has grown rapidly in importance during recent years is designed for the meat-carrying trade, and is fitted with refrigerating machinery for cold storage. A description of the special appliances on these vessels belongs to the field of engineering rather than to shipbuilding. In the year 1904 over 150 large ocean-going steamers were employed in this trade. One of the most recent is 470 ft. long and carries 100,000 carcasses of mutton. The dead-weight capacity is 10,000 tons, and the speed 13 knots. This is an exceptionally large vessel for the trade. It is said that the aggregate of 9,000,000 carcasses was the capacity of 147 vessels recently engaged in the frozen meat trade. These figures will afford an idea of the importance of this branch of commerce, and of the influence such a large addition to the food supply of the nation has upon our domestic economy.

CHAPTER VII.

HISTORICAL SKETCH OF THE DEVELOPMENT OF THE STRUCTURAL FEATURES OF IRON AND STEEL SHIPS.

THE structure of a ship is subject to a variety of strains of both local and general character, due to the many stresses, when afloat and ashore, which it has to undergo. The structural arrangements are intended to meet these stresses and it is of the highest importance that, in the distribution of the material, lightness should be combined with strength, not merely for the sake of any diminution in first cost which may result from getting rid of unnecessary material, but also because the existence of such material naturally diminishes the cargo-carrying capacity, and therefore the earning power of the merchant vessel, and, in the case of warships, reduces the weight which can be put into the armour, armament and engines. Hence it is necessary that designers should have an accurate knowledge of the character and amount of the stresses to which ships may be subjected.

The precise determination of the intensity of the stress on any given part of a ship is, for several reasons, a much more difficult task than is the corresponding problem in the case of a land structure, such as a bridge or a roof. The stresses undergone by bridges and roofs are of a relatively simple character, and easy to determine. These structures always occupy fixed positions, and the external forces are generally brought to bear upon them in the same manner. Moreover, in modern examples they are generally articulated,

that is to say, composed of booms, struts, and ties jointed together, and it is a simple problem to resolve the forces to which they are subjected in the direction of these members; also the sectional areas of the various articulated elements being perfectly well known, it is easy to find the intensity of the stresses at any point.

Now, the case of a ship differs entirely from the foregoing. The greater part of its structure is made of continuous plates in which it is impossible to ascertain the exact distribution of the stresses. Furthermore, a vessel never occupies a fixed position except when it is aground, in dock, or afloat in perfectly still water, and consequently the forces brought to bear upon its structure are constantly varying both in direction and intensity. For instance, when rolling at sea, the portions which, when the vessel is upright, form the top and bottom of the structure may become the sides, and will have to bear all the stresses incidental to the web of a girder,* instead of those incidental to its top and bottom flanges. Again, when a vessel is afloat in still water it undergoes certain longitudinal stresses, depending upon its dimensions and the amount and distribution of the weights of its structure, fittings and cargo, relatively to the supporting forces, *i.e.* to the buoyancy at the different parts of the hull. If the vessel be taken from still water and placed among waves, say, of its own length, trending fore and aft in direction, the character and intensity of the longitudinal stresses will vary immediately, and from moment to moment, because the supporting forces are constantly changing in position. For instance, when the crest of such a wave is underneath the central portion of the vessel, the bow and stern will be in the trough of the sea and, therefore, relatively unsupported. The next instant both bow and stern may be deeply immersed in the crests of two successive waves, while the

* For an explanation of these terms see Appendix I,

centre is in the hollow between them, and it is then relatively unsupported. In the first instance the ship somewhat resembles the case of a beam supported under its centre alone, the ends having a tendency to droop, and the whole beam has a tendency to curve like a hog's back; while in the second case the conditions are exactly reversed—the ship resembles the ordinary case of a bridge, or beam, supported at the ends; the centre consequently tends to droop, and the beam has a tendency to curve down, or sag. Hence the origin of the terms "hogging" and "sagging" stresses. It will be shown that, when the centre alone is supported, the material in the top of the structure is in a state of tension and that in the bottom in compression; while, when the supports are transferred to the ends the strains are exactly reversed.* Hence it may happen that, when a vessel is steaming across waves of her own length, the character of the strains in her upper works and bottom may alter violently in character and direction several times per minute. Now, it is a well-known fact that a structure requires to be made considerably stronger when it is subjected to stresses which are frequently reversed, than when those stresses are invariable in direction.

The foregoing instances by no means exhaust the conditions which have to be allowed for in a ship and which do not enter into the design of land structures. Rolling and pitching among waves, for instance, cause notable variations in the stresses. Then, again, the cases of the vessel being bodily lifted above, or depressed below, the normal plane of flotation have to be considered.

Again, the vessel occasionally takes the ground, and may do so in a number of ways. For instance, it may ground somewhere about the middle of its length, leaving the ends to be supported by the water, and the character of the water

* See Appendix I.

support may vary from hour to hour, according to the height of the tide, and even several times in the minute, if the vessel in addition to being grounded, is amongst waves; or, on the other hand, one end may take the ground, as in the case of H.M.S. *Victoria*, referred to on page 53, while the middle and other end are wholly, or partly, supported by the water.

The general transverse strength of the ship has, moreover, to be carefully provided for under various conditions afloat and ashore, including the case of resting on the keel only, when in dock; and when all these various problems of general straining action have been considered and allowed for, the ship designer may still make serious mistakes in fixing the scantlings of the various parts, if he does not take local conditions into account. For instance, theoretical considerations regarding the general structural strains would lead him to reduce the scantlings towards the ends of the vessel; but the after-ends are very frequently subjected to special local strains in connection with the propelling apparatus; while the wear and tear connected with working the anchors, and the probability of undergoing heavy rubbing and grinding, and even collisions, affects the bow. Then, again, every part of the skin of the ship must be made sufficiently strong, and be sufficiently well supported from within to withstand the collapsing tendency due to the pressure of water, or any local pressure due to the weight, or movement, of the cargo. Moreover, in fixing the scantlings of the various parts they must not only be chosen sufficiently strong to withstand effectually all the stresses when the vessel is new, but a certain extra allowance must be made to provide against the eventual loss of material due to corrosion.

From the foregoing remarks, which only touch lightly upon a few of the many considerations which have to guide the shipbuilder, it will readily be seen that his task in designing the

structural features of vessels is no light one. His object should be to so proportion, distribute and combine the material, that each part may help, as far as possible, in meeting all the stresses to which the structure is subjected.

An elementary examination of some of the principal external forces which act on ships in smooth water and among waves and of the stresses which these forces produce in the structure of vessels is given in Appendix I. It is intended for the use of students who visit the Museum, to enable them the better to appreciate, from an engineering point of view, the numerous structural arrangements illustrated by models in the galleries. For the general reader this Appendix will perhaps be found somewhat too technical, but he will have no difficulty in understanding, without its help, the general objects of the various structural features, an account of the gradual development of which from the early days of iron shipbuilding will now be given.

As might have been expected, when the earliest iron ships were built the principal features of wooden shipbuilding were largely copied. Hence it arose that the system of transverse framing became almost universally adopted in the building of merchant ships. There was only one notable exception to this rule. It was found in the practice of the late Mr. John Scott Russell, F.R.S., who, as far back as the year 1835, built an iron vessel with longitudinal frames. As Mr. Scott Russell's system and the more recent developments and modifications of the same have played, and are now playing, a most important part in the practice of shipbuilding, it will be described more particularly later on.

As shown in Fig. 64, the earliest iron ships consisted of iron sides and bottom, kept in shape and stiffened against transverse and local strains by a series of transverse frames, to which the deck beams were attached. The frames were generally

formed of angle irons, riveted to the skin plating and spaced about 20 in. to 24 in. apart. Every frame had a second, or reversed, angle iron riveted to it on the inner edge. Across the bilges and bottom of the ship the frames were expanded

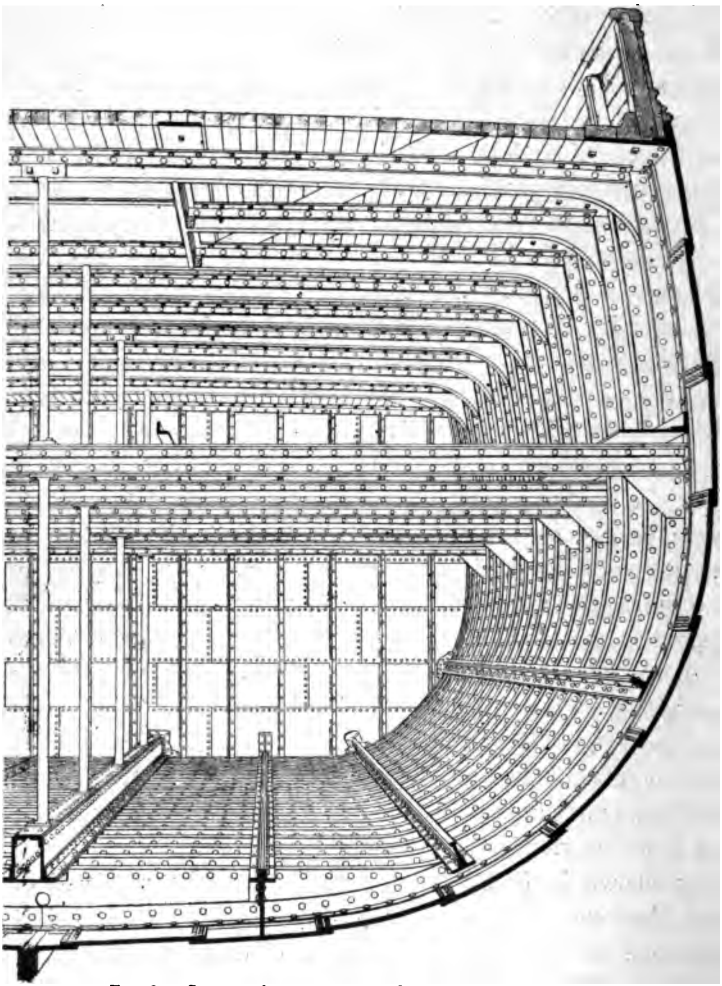


FIG. 64.—Structural arrangements of transversely framed ship.

out into plate girders, which follow the form of the bottom and are called the floors. The angle irons by which these floors were fastened to the bottom and bilge plating were the continuations of the frames proper. It is evident that the transverse frames could contribute nothing to the longitudinal strength of the ship, which was secured mainly by the upper skin plating, the deck planking, the bottom plating, and the keel. The ships of those early days were generally small, and theoretical calculations have shown that the longitudinal strains experienced by small iron ships are very moderate. The scantlings were fixed by considerations affecting local stiffness, and were found to be sufficient to provide amply for the general longitudinal strength. As, however, the size of iron ships increased, so also did the intensity of the maximum longitudinal stresses, and new methods of strengthening had to be devised. On the bottom over the floor plates, and immediately above the keel, a strong continuous keelson was laid, which often took the form of a stiff flanged girder. Side keelsons were also made use of. As shown in Fig. 64 these consisted of web plates fitted intercostally between the floor plates, and attached by angle irons along their lower edge to the bottom plating, and by similar angle irons at their ends to the floor plates, while the top angles were continuous and overrode the floor plates. Other keelsons ran continuously fore and aft above the floor plates, in the neighbourhood of the bilges. A similar, but lighter member, called a bilge-stringer, was fitted so as to override the transverse frames above the turn of bilge; while, occasionally, bilge-keels were attached to the outside of the bilge plating over a considerable length of the ship. In this way the bottom and bilges of the ship were provided with considerable longitudinal strength and stiffness, to resist the local strains which might arise from taking the ground, and

from the concentration of weights in the hold. In order to endow the upper parts of the ship with a corresponding degree of strength, the decks were partially plated along their whole length close to the side-skin. These partial platings which are called deck-stringers were firmly attached by angle irons to the skin of the vessel. They resemble the upper flanges of girders, and the reader who follows the theoretical matter in Appendix I. will have no difficulty in understanding the important part which they play in contributing to the longitudinal strength. Further strength was given to the upper works by increasing the thickness of, or doubling, the sheerstrake, by which name the uppermost strake of the skin plating is called.

A further and later development was the complete plating of one, or more, of the decks with iron, which had the effect of converting the ship into a structure similar to a box girder.

By means of these additions to the structure, it is obvious that a ship whose principal framing was transverse could be provided with very considerable longitudinal strength. On the other hand, this system of construction is theoretically a faulty one; because, whereas the principal strains experienced by ships are longitudinal, the main framing in this kind of structure is transverse, and does not contribute directly to strengthening the ship in the direction in which it is weakest. Nevertheless it continued to be almost universally employed in the construction of merchant vessels till about the year 1877. This was due, probably, to the fact that it was the only system which had ever been understood in the majority of private yards, that it was simple, cheap, and easily carried into execution, and that, although the material, if otherwise distributed, would have given greater strength, nevertheless it gave amply *sufficient* for vessels of the sizes common in those days, when

built to the scantlings which were rendered obligatory by the large registration societies.

Mention should here be made of the interesting historical fact that in the case of that extraordinary vessel, the *Great Britain*, commenced in the year 1839, many of the improvements alluded to above as successive developments, were anticipated, as shown in the section of this vessel (Fig. 65). We find that in the *Great Britain* deck-stringers were used, and the bottom was strengthened by ten longitudinal plates, or stringers, set vertically, so as to override the transverse frames, to which they were connected by angle iron bracketing, while the top edges of these stringers were connected by angle irons to a so called lower cargo deck of plate-iron, which was, in effect, an inner bottom. This vessel was further provided with two partial fore and aft bulkheads, which bounded the sides of the engine room. They also formed the sides of the coal bunkers and, had they been combined with a partial iron deck, they would have added greatly to the longitudinal strength of the ship. The transverse rigidity and the safety in case of collision were provided for by five water-tight transverse bulkheads. The power of the decks to contribute to the longitudinal strength of the ship was further increased by the use on the two upper decks of ponderous timber water-ways, the lengths of which were scarfed together and bolted to the frames and deck-stringers, and ran from end to end of the ship. The lower of these two decks was further provided with a massive timber shelf-piece similarly secured, and the greatest care was taken to utilise the upper deck planking to the fullest extent in resisting the longitudinal stresses. With the same object in view, the sheerstrake was reinforced by means of a continuous outer strap 6 in. wide by 1 in. thick, and an inner strap 7 in. by 1 in. riveted to it.

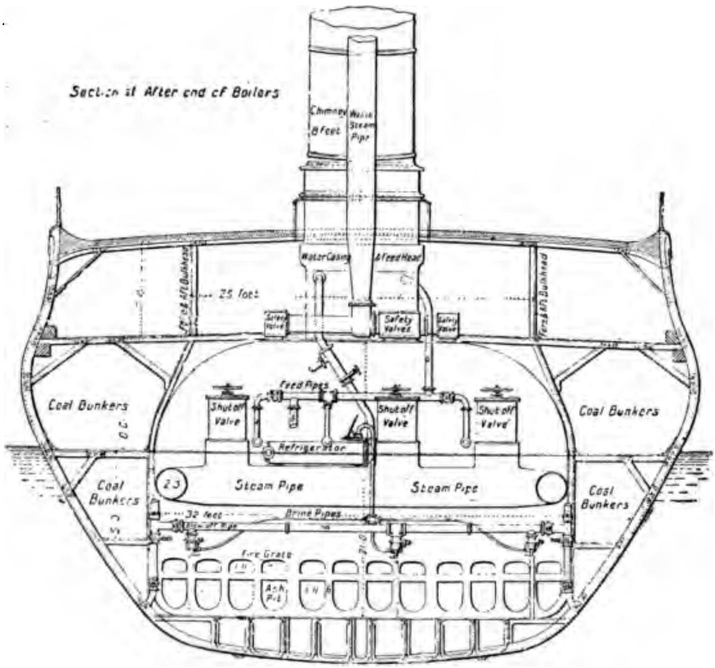


FIG. 65.—Cross section of the *Great Britain*.

When we consider that this vessel was built in the very infancy of iron shipbuilding, that she was of large size, having been 322 ft. long, over all, by 50 ft. 6 in. beam, and displaced 3,618 tons at her load draught of 18 ft.; and when we further remember that she was built before the days of wrought-iron bridges, and that there was absolutely no precedent either in land or sea structures to instruct her designers, and that the principles which guide us in ascertaining the stresses and in calculating the strength of iron structures were very imperfectly understood—it is impossible to withhold from Mr. Patterson, her constructor, and Mr. I. K. Brunel, her designer and the consulting engineer of the steamship

company which built her, the greatest admiration for their combined prescience and audacity.

No fault can be found with the transverse system of framing from the point of view of resisting local and transverse strains. It is obvious that the frames, spaced at such close intervals as 20 in. to 24 in., and combined with continuous longitudinal stringers (which serve to distribute the effect of local stresses) form an admirable means of supporting and stiffening the skin. All the portions of the ship which have been enumerated combine in resisting transverse distortion. Each transverse frame, with the section of skin plating on either side belonging to it, together with the deck beams attached to it by knee pieces, the section of deck plating and planking belonging to each beam, and the pillars which support the beams, form in combination a very stiff ring, or hoop, which it would be difficult to distort. Any force tending to bring the two sides closer together and to camber up the deck beams is resisted, not only by the stiffness of the combined frames and plating, but also by the direct power of the beams and their associated deck plates and planks to resist compression, and by the power of the pillars to resist tension. The latter, it should be observed, should always be so fastened as to be able to transmit forces of compression or of tension. The power of the various keelsons and longitudinal stringers to resist the bending forces which may be transmitted to them by the frames, also contributes to the transverse strength, and in the case of severe local transverse strains these longitudinals, and also the skin-plating, serve to distribute the local stress over a considerable area, and thus call into play the resisting power of all the neighbouring frames, beams, etc.

When the forces tending to distort the transverse section of the ship bring the bottom and decks closer together, the pillars are put into compression. If the section were a true

ring, any tendency in this direction would be followed by a corresponding increase of the distance between the sides, which would result in the deck beams being put into a state of tension. When severe local strains, such as those due to grounding, are transmitted upwards through the bottom, they are met, in part, by the power of the deep floors to resist bending, but some of the strain is transmitted through the pillars to the deck beams, and is there met, partly by the power of the latter and of the deck plating to resist bending, and partly by the fact that the deck beams, if slightly bent, must tend to draw the sides together, and in so doing bring into play, through the agency of the stringer plates, the power of the transverse frames and of the skin plating to resist bending. In this way the resisting powers of most of the main features of the structure are called into play to meet any distorting force, and if the latter should be of a local character the various longitudinals serve to distribute its effect by calling into action the resistance of all the neighbouring parts.

Other features in the structure which contribute most powerfully to the transverse strength of ships are the water-tight transverse bulkheads, which, formed of solid plate, stiffened when necessary with angle irons and girders, are united firmly to the sides, bottom, and decks of the vessel at intervals throughout her length, and constitute, when properly constructed and supported, sections of practically unchangeable form, which also serve as points of support to the various longitudinal girders and stringers. In this respect they correspond pretty closely with the abutments and intermediate pillars of bridges formed of continuous girders. If it were not for their support the longitudinals of a ship, in consequence of their great length compared to their depth, would have little power to resist bending.

Transverse bulkheads were originally introduced for the

purpose of preventing the ship from foundering when laid open to the sea by grounding, collision, gunfire, etc. Their effect, when carried high enough, is to divide the hull into a number of water-tight compartments, no one of which, when put in communication with the sea, should be large enough to compromise the vessel's power of flotation. In order to fulfil this purpose their mechanical structure must be such that they will not give way, or leak, when put under the pressure, often very severe, of the head of water which acts on them when the compartment which they bound is filled with water.

The system of framing vessels which has just been described continued to be adopted for merchant vessels almost universally down to about the year 1877. Another system, in which the frames were all laid longitudinally, and in which transverse frames were wholly dispensed with, was, as already mentioned, introduced as far back as the year 1835 by the late Mr. John Scott Russell. In that and the following year this famous naval architect built

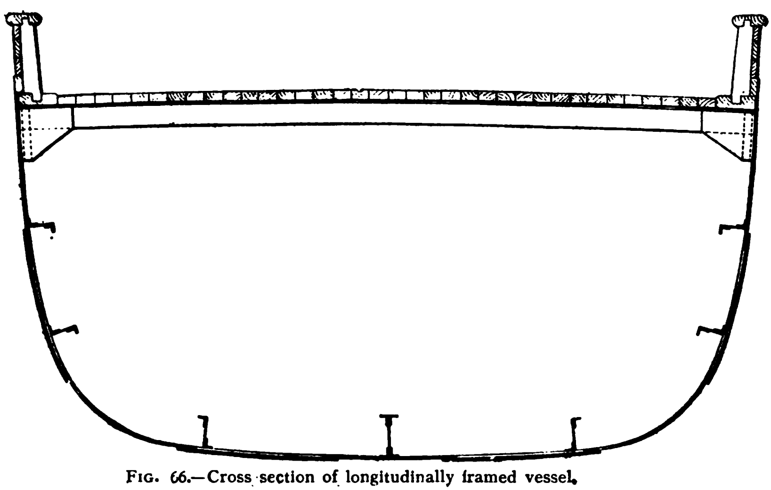


FIG. 66.—Cross section of longitudinally framed vessel.

three iron vessels, the first of which was kept in shape by a longitudinal middle-line bulkhead with four transverse bulkheads connected by longitudinal stringers, and had absolutely no transverse frame. The two others were built without the longitudinal bulkhead, but with more numerous transverse partitions and longitudinals. It was not easy for the inventor to continue the system at that time, because it required more skill than did the older plan to put into execution. Moreover, as the method was not then recognised by the registration societies, owners of vessels naturally set their faces against it. Hence it was that we find but few examples of this kind of framing in the early iron ships.

In the year 1850, however, Mr. Scott Russell had the opportunity of applying the system to a small screw vessel which was used in working the traffic between the railway systems on the opposite sides of the river Humber. Fig. 66 shows a transverse section of this vessel, through the longitudinals, and Fig. 67 through a partial bulkhead. It will be noticed that a longitudinal is riveted to each of the strakes of plating in the bottom and hull, excepting only the sharply curved strake at the turn of the bilge on either side. The riveted seams in these longitudinals were so arranged as to break joint with those in the strakes of plating. The partial bulkheads shown in Fig. 67 are an important feature in this type of construction. They are introduced between the complete bulkheads to give transverse rigidity to the ship. They are formed of deep web plates fitted between the longitudinals, fastened by an angle iron to the shell plating, and also stiffened along the inner edge with an angle iron. They are described by Mr. Scott Russell as being, practically, ordinary transverse bulkheads with the whole of the centre portion removed. In the same year Mr. Scott Russell constructed a paddle-wheel steamer 145 ft. long on the water-line, 15 ft.

wide, and 7 ft. 6 in. deep, also on the longitudinal principle. It will be noticed that the length was just eighteen times the depth, and it would not have been easy on any other system to have given a vessel of such unusual relative length the requisite longitudinal strength. The system as applied answered perfectly. These vessels were followed at intervals, whenever the builder was allowed a free hand, by others built on the same principle. One of the most remarkable of these was a

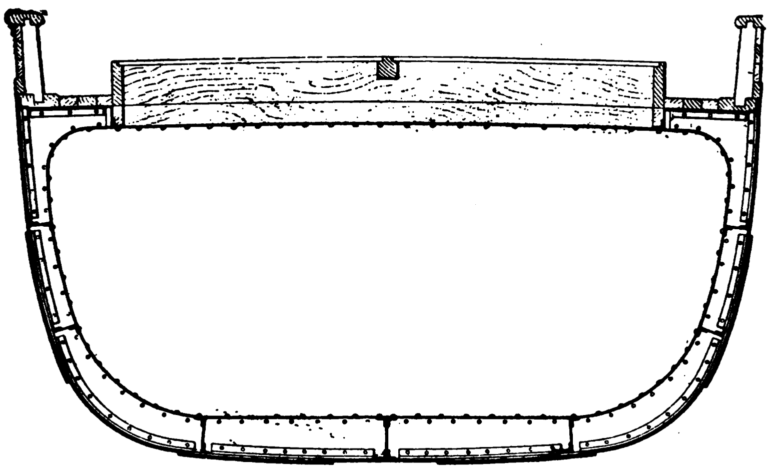


FIG. 67.—Cross section of early longitudinally framed vessel.

shallow paddle-wheel vessel, built for towing on the Rhine, and called the *Rhenus*. This boat was of very light draught and of great length relatively to her depth. The following were her principal dimensions :—Length on load water-line, 186 ft.; length over all, 197 ft.; breadth, extreme, 25 ft.; depth at side, 9 ft.; draught of water, 3 ft.; ratio of length to depth, 21·9 : 1. This vessel was built with exactly the same structural arrangements as the boats previously mentioned, viz., with a longitudinal stringer on each plate except

the bilge plates. The side stringers were arranged in horizontal planes and corresponded with the flanges of an ordinary girder. The top stringer was on the level of the deck. Many larger vessels were built afterwards, among them the *Baron Osy* and the *Rey Jaymes II.*, which were framed longitudinally in the central portions between the transverse bulkheads bounding the engine and boiler spaces, while the rest of the vessel was framed transversely.

Before describing the structural arrangements of any of the more advanced types of longitudinally framed ships, it may be as well to refer briefly to the *Victoria* and the *Adelaide*, vessels of great interest, built for the Australian trade by Mr. Scott Russell in the year 1852 and designed, as already stated (see page 32), by him and by Mr. Brunel, who was the consulting engineer of the company which owned them. It was pointed out, when describing the *Great Britain*, that some of her structural features, notably the fore and aft bulkheads which formed the coal bunkers, would, if they had been properly carried out and combined with a partial iron deck, have contributed greatly to the longitudinal strength. Mr. Scott Russell was an advocate of this combination in the middle portions of iron ships,* and it was introduced, for the first time, in the *Victoria* and the *Adelaide*. These vessels were not built on the longitudinal system, probably because of the difficulty of getting ships classed that did not comply with the rules of the registry societies.† They were built with the ordinary transverse frames and flat floors. The longitudinal strength of the bottom was provided for by running a central box keelson

* *Transactions, Institution of Naval Architects*, vol. i. pp. 88, 89.

† A few years later Lloyd's Registry lent Mr. Scott Russell every assistance, and classed several longitudinally framed ships, notably the *Baron Osy*, the *Rey Jaymes II.*, and the *Annette*.

over the top of the floors at the centre line. The keelson was provided with a very wide bottom flange, as shown in Fig. 68, which is a cross section of this vessel through the boiler

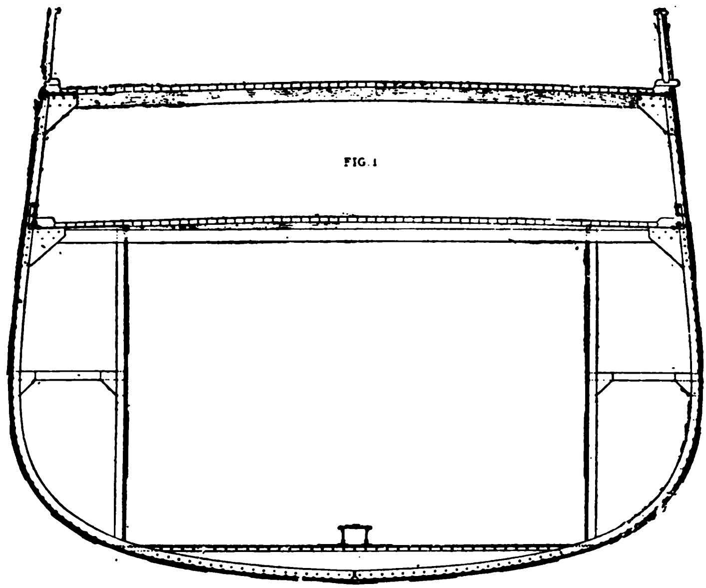


FIG. 68 —Cross Section of the *Adelaide*.

room. Longitudinal bulkheads bounding the coal bunker are shown, carried up to, and attached to, the main deck, and the whole of the deck between the heads of these bulkheads and the sides of the ship is plated. Thus the sides of each ship, the wing bulkheads, and the deck and bilge plating formed two strong box girders, which, of course, contributed greatly to the longitudinal strength. These vessels were also fitted with several complete and partial bulkheads. They never showed the slightest signs of structural weakness, though of large size, their principal dimensions having been—length on load waterline, 261 ft.; extreme breadth, 38 ft.; depth at the side, 27 ft. 8 in.; displacement laden, 3,000 tons. They were

each fitted with a detachable screw propeller, and won the prize given by the Australian Colonies for the fastest passage out to Adelaide.

The *Victoria* and the *Adelaide* are historically remarkable for two reasons. Firstly, because their peculiarities of structure—viz., the longitudinal bulkheads and partial iron decks—formed, when combined with the longitudinal system of framing, the main elements in the structure of that triumph of iron ship construction, the *Great Eastern*; and secondly, because their inability to pay a return to their owners, under the then existing conditions of fuel consumption in the engines, was one of the main reasons which caused the late Mr. Brunel to conceive and recommend the building of that great vessel; the structure of which marked an epoch in the history of shipbuilding.

It would be out of place here to consider all the commercial reasons which led to the building of the *Great Eastern*. Her general characteristics have already been described (*see* pp. 33 to 36), and we have now only to consider her mechanical structure, which was designed by Mr. Brunel and Mr. J. Scott Russell. These two famous engineers, some time before the project assumed a mercantile form, worked out together the main features of the structure, as well as the form and dimensions of the ship. Mr. Scott Russell afterwards became the builder, and Mr. Brunel the consulting engineer of her owners, the Eastern Steam Navigation Company, and in this capacity he was responsible to the shareholders for the whole of the design. Mr. Scott Russell's system of longitudinal framing, combined with numerous complete and partial bulkheads, as already described, was adopted as the main feature of the construction. To this were added the longitudinal bulk-heads, forming the boundaries of the engine and boiler spaces, combined with an

iron deck on each side connecting the heads of these bulkheads with the skin of the ship, as already described in the case of the *Victoria* and the *Adelaide.* It will be observed from the sketch cross section (Fig. 69) that in the *Great Eastern* these features,

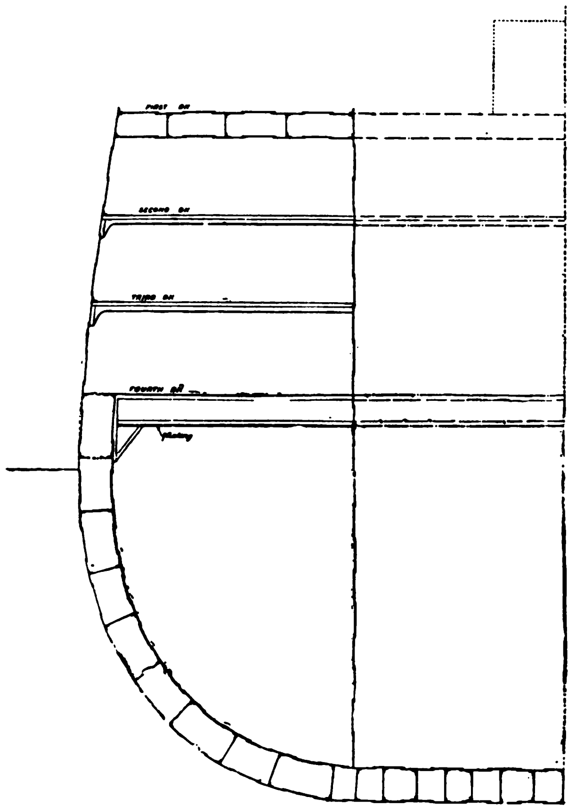


FIG. 69.—Cross section of the *Great Eastern.*

which contributed so much to the longitudinal strength of the structure were greatly improved and developed. In the first place, the longitudinal bulkheads, which in the Victoria and

her sister ship naturally stopped at the main deck, were in the *Great Eastern* carried right up to the uppermost deck, which is perfectly flush and runs from end to end of the ship. The iron deck connecting the head of each longitudinal bulkhead with the ship's sides is thus placed at the greatest possible distance from the bottom of the girder, that is to say, in the position which contributes most to the longitudinal strength. In the next place, the deck itself is a remarkably strong structure. Encouraged by the success of the Britannia Bridge over the Menai Straits, the top and bottom flanges of which are of cellular construction, Mr. Brunel suggested and adopted for the great ship not only a cellular bottom, but also a cellular upper deck. The latter consisted of an upper surface of two layers of ½-in. plates, riveted together, and supported on longitudinal girders to the lower angle irons of which were riveted two similar layers of ½-in. plating; the length of the plates ran in the direction of the length of the ship, and the butt joints of the upper and lower surfaces were arranged so as to break joint. This system of structure applied only to the portions of the upper deck between the heads of the longitudinal bulkheads and the sides. It was only in these portions of the ship that the deck could be worked continuously fore and aft; for, in between these bulkheads were situated the immense saloons and the engine and boiler spaces, the skylights of all of which formed vast openings in the deck. Between these openings, however, where possible, the deck was carried right across and supported on transverse beams, and thus the two sides of the ship were firmly joined together at the highest structural level. In this way the top flange of the girder was made of great strength. For the purpose of resisting the tensile stresses on the upper works, an ordinary iron deck, supported, in the usual way, on transverse beams, could

have been made amply strong enough; but to resist strains of compression, which would tend to buckle very large, flat, thin surfaces, the cellular form of structure is probably the best that could have been adopted.

It will be noticed that the bottom and sides of the ship were also built on the cellular system, as high up as the fourth deck. A longitudinal web about 2 ft. 10 in. deep was riveted to every alternate strake of plating as far up as this deck, and along the flat bottom portion there was on each strake of plating a web, which furnished the bottom with additional strength to meet the local strains due to grounding. Above the fourth deck the longitudinals were discontinued, and their places taken by the ordinary deck-stringers. The inner bottom and inner sides constituted in all respects a second ship inserted within the outer one. The inner skin not only added to the strength of the structure, but also served two other useful purposes: it greatly added to the safety of the ship in cases of collision, or of running on rocks, and it provided means of utilising water as ballast in the spaces between the inner and outer skin, to the extent of about 2,500 tons. The inner skin was continued right up to the bows, so as to afford additional chances of safety in case of collision with icebergs, but it was not continued to the stern, because it would there have been inconvenient and unnecessary; the size of the water-tight compartments into which this part of the vessel was divided by means of the transverse bulkheads and water-tight flats having been such that, even if more than one of them had been opened to the sea, no danger would have resulted. Both inner and outer skin were formed of plates which would be considered ridiculously small in these days. The dimensions of the outer plates were—length, 10 ft.; width, 2 ft. 9 in.; thickness, ¾ in.; and weight, 810 lbs. each. The longitudinal webs between the two skins were formed of plates ½ in. thick,

and attached by angle irons, 4½ in. by 4½ in. It is worthy of remark that in the whole of the structure, with the exception of the keel plates, only two thicknesses of plates, viz. ¾ in. and ½ in., were used, and only two sizes of angle iron. The

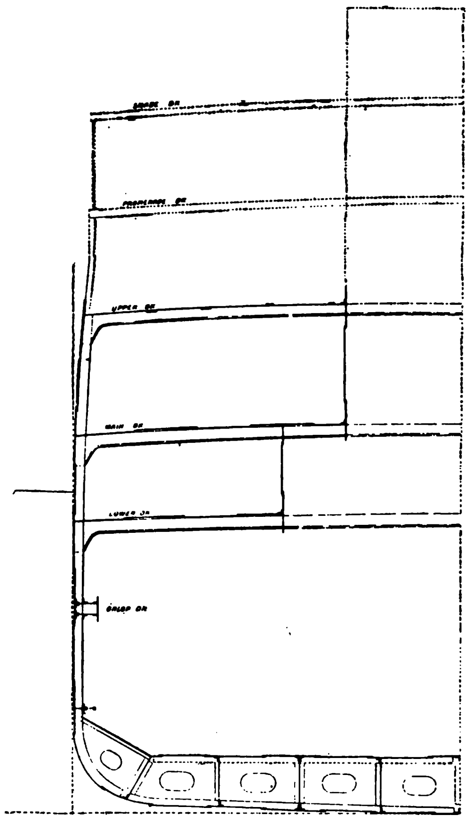


FIG 70.—Cross section of the *Campania.*

keel plates and their longitudinal web were formed of inch plates. The utility of the double bottom, apart from considerations relating to the strength of the ship and to its capacity *for carrying* water-ballast, was proved by the fact that the

ship was saved by the inner skin remaining intact after the accident described on page 36.

It may be interesting at this point to compare the structure of the *Great Eastern* with that of a modern ship, such as the *Campania*, as shown by the respective cross sections, Figs. 69 and 70.

The dimensions of the two vessels have already been given but may here be repeated for the sake of comparison.

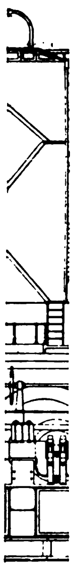
	Great Eastern.	*Campania.*
Length over all	692 feet. ..	622 feet.
Length between perpendiculars ..	680 " ..	600 "
Breadth, moulded	82 " 2 in.	65 "
Depth, moulded, to upper deck ..	58 " ..	41 " 6 in.

It will be noticed that the inner skin of the *Campania* is limited to the flat portion of the bottom, whereas in the *Great Eastern* it is carried up well above the water-line. There are, round the entire hull of the *Great Eastern*, forty-three longitudinals including the deck-stringers and the double iron deck, while in the *Campania* there are twenty-one. The transverse strength of the *Great Eastern* is secured by bulkheads, as explained on page 154, while the *Campania* is transversely *framed* throughout. In the *Great Eastern* there are two longitudinal bulkheads, reaching from the inner bottom to the upper deck; these play a most important part in transmitting the strains to the upper and lower flanges of the girder. In the *Campania* there are no such bulkheads. But, perhaps, the most remarkable difference is in the upper flanges of the girder in the two ships. The total depths reckoned from the flush upper deck in the *Great Eastern* and from the shade deck in the *Campania* are approximately the same; but, whereas the uppermost deck of the former ship constitutes the top flange of the girder, and is 58 ft. above the bottom, the two upper decks of the latter are not real structural features of the ship, but are platforms added to the hull and supported on pillars, while the true construction upper deck is only 41 ft. 6 in. above

the bottom. Thus we see that, regarding the two ships as girders, and taking the lengths between perpendiculars, the *Great Eastern* is 11·7 times as long as she is deep; whereas the length of the *Campania* is 14·45 times her depth. The importance of her great relative depth in enabling the *Great Eastern* to withstand longitudinal straining will readily be appreciated by those who have studied the theory of this subject. To compensate the *Campania* for her comparative shallowness, she is fitted with three plated decks, against one in the *Great Eastern*, and her shell plates are also one-eighth of an inch thicker than those of the larger ship.

Returning now to the description of the structure proper of the *Great Eastern*, as shown in the longitudinal section, Figs. 71 and 71A, on the folding plate, it should be noted that her transverse strength is secured on the same principles as that of the early longitudinally framed ships built by Mr. Scott Russell, which have been already described; that is to say, there were no transverse frames whatever, but numerous complete and partial transverse bulkheads. There were ten complete transverse bulkheads, which extended right across the ship, and from her bottom to her upper deck. There were three additional bulkheads, which extended right across the ship from the bottom to the fourth deck, which latter was well above the water line. These three bulkheads could not be carried any higher, because they would have interfered with the saloons. There were thus, in all, thirteen bulkheads right across the ship dividing the hull below the fourth deck into fourteen watertight compartments, each of which latter, in the central portions of the ship, was further subdivided into three divisions by the two longitudinal bulkheads.

In between these main transverse bulkheads were many partial ones, corresponding in width to the space between the two skins, while above the fourth deck they were much more



: *Great* .

numerous. The main bulkheads were supported by vertical stiffening plates attached to them by angle irons, and spaced about five feet apart. They also, of course, derived great support from the numerous decks and from the two longitudinal bulkheads, which latter they in their turn supported. The transverse strength was further secured by the cellular iron upper deck, and by the cellular structure of the double sides and bottom, as well as by the numerous intermediate decks.

Such were the main features of the structure of the *Great Eastern*. They have been described at some length, not only because this vessel was, on account of her enormous size and the novelty of her arrangements, the most remarkable iron ship that was built in the 19th century, but also because many of the structural features which were introduced in her design have, after a long interval, been again adopted in modern practice. In spite of the novelty of the problem presented to her designers, the *Great Eastern*, as a mechanical structure, was a complete success, never having shown the slightest signs of structural weakness.

In the year 1861 Mr. Scott Russell built, entirely on the longitudinal system, an iron auxiliary screw clipper of 845 tons, builders' measurement, called the *Annette*. The structure of this vessel is very clearly illustrated in Fig. 72. It will be noted that no transverse frames were used. Their place was taken by deep transverse partial bulkheads and by longitudinal stringers, one of which is riveted to every strake of the skin plating, except the upper one, where there was a continuous iron deck supported on the complete and partial bulkheads and stiffened by longitudinal tie irons and girders. The partial bulkheads and the longitudinal stringers are of the same depth and, where they intersect, they are united to each other by so-called diamond plates.

The dimensions of this vessel were—length, 190 ft.; breadth, 30 ft.; depth at side, 18 ft.; depth in hold, 18 ft. 3 in.

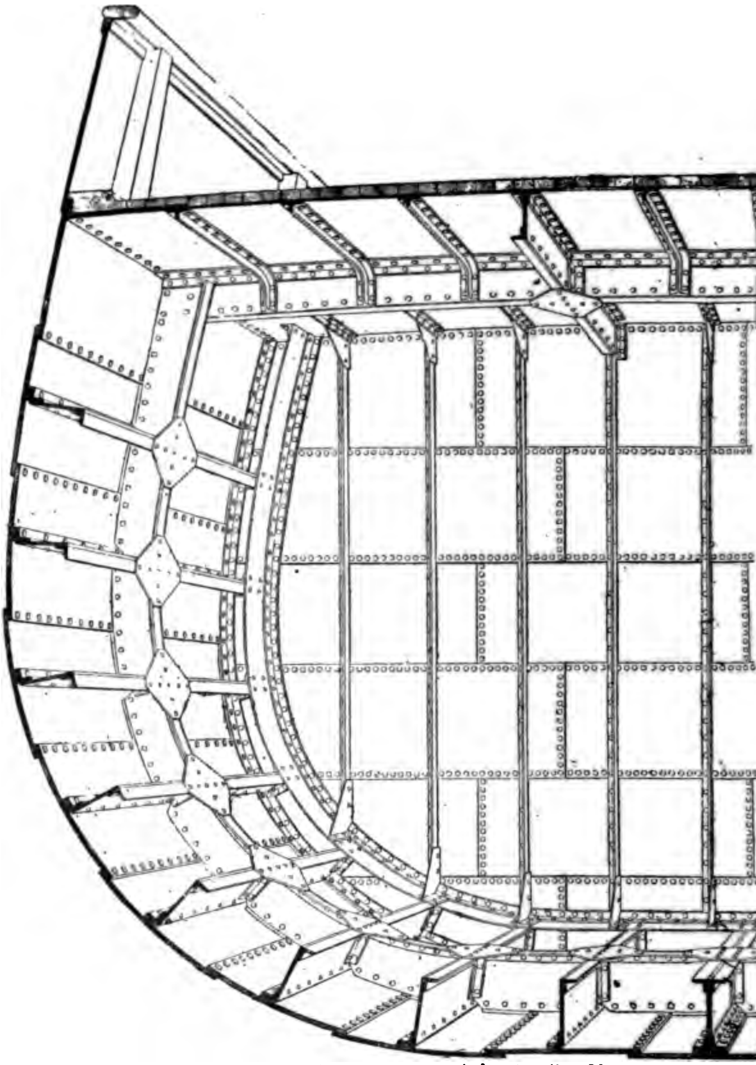


FIG. 72.—Structural arrangements of the *Annette*, 1861.

She was provided with five complete and with ten partial bulkheads, each 13 ft. apart. The builder stated that the effective section of the metal which resisted longitudinal stress in this vessel was 650 square inches, against 520 in a similar vessel transversely framed, that is to say, there was a gain of 25 per cent. in the amount of effective cross section, and a glance at the arrangement will show that the material is admirably placed for the purpose of resisting bending strains.

In spite of the success of the *Great Eastern* and the *Annette* the longitudinal system of shipbuilding did not find favour with the builders of merchant vessels. The reasons have been already indicated. With the scantlings, which considerations of local strength render necessary, the moderate-sized vessels of those days that were built on the transverse system possessed ample longitudinal strength, especially when provided with one or more iron decks. Builders, therefore, did not consider it necessary to adopt the longitudinal system, to which their workmen were not accustomed, and which was somewhat more difficult and more costly. It was not till some fifteen years after the building of the *Annette* that the general introduction of water ballast caused builders again to take up a system of framing in which the longitudinal element predominated. Before, however, describing the system of construction which resulted from the introduction of water ballast, we must glance at the important work which was being done at the Admiralty in developing the structural features of iron ships of war.

The *Warrior*, which was the first sea-going ironclad built in this country, was designed by the constructive department of the Admiralty, in agreement with the views of the late Mr. J. Scott Russell. As might perhaps have been expected, her structural arrangements are a combination of the longitudinal

and transverse systems of framing. The principal dimensions of the *Warrior* and a general description of the vessel have already been given (*see* pages 50 to 52). She was completed in the year 1861.

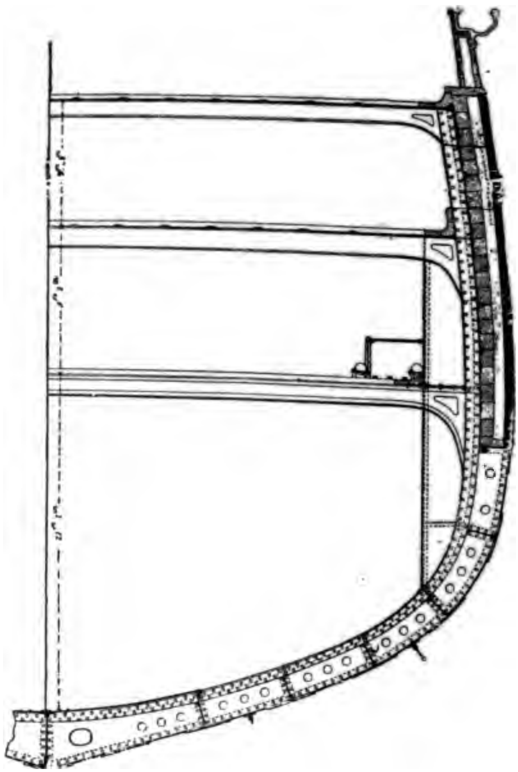


FIG 73.—Cross section of H.M.S. *Warrior*. Commenced 1859.

Fig. 73 shows her cross section. It will be noticed that there are six longitudinals on each side of the keel, the upper one on each side being used as a shelf for supporting the armour and backing. These longitudinals are continuous. The transverse strength is obtained by fitting plate frames intercostally

between the longitudinals, their upper, or inner edges being connected by continuous transverse frames made of plate and angle irons, which are carried above the armour shelf to the upper iron deck, very much like ordinary transverse ribs. The angle irons on the outer, or bottom, edges of the longitudinals are double, while on the upper, or inner edge they are single. The longitudinals do not run the entire length of the ship; they extend for a length of from 280 to 320 ft., and terminate at transverse bulkheads, the remainder of the ship at the extreme ends, fore and aft, being framed transversely. Above the armour shelf, on either side of the ship, are two continuous longitudinal stringers embedded in the backing. The transverse frames are spaced 3 ft. 8 in. apart, except at the ends of the ship, where the distance between them is only 22 inches. Between each pair of main transverse frames an intermediate partial frame is worked from the upper deck to the third longitudinal. It will be observed that the transverse plate frames fitted between the longitudinals are formed of solid plates, lightened by having three holes cut in each of them. It is important to note this point, as one of the earliest improvements made on the structure of the *Warrior* had reference to these frame plates. In addition to the internal longitudinals, two external bilge keels were fitted to each side over a considerable portion of the vessel's length.

A further and most important contribution to the longitudinal strength consisted in a vertical longitudinal watertight bulkhead, which extends from the main deck down to the third longitudinal in the bottom on each side. The top edges of these bulkheads are secured to the iron plating of the main deck. They are also secured to the lower deck-stringer, and thus form, with the sides of the ship, very strong box girders, similar in principle to the arrangements already described in the case of the *Adelaide* and the *Great Eastern*. It may

here be noted that the spaces between the sides of the ship and the vertical, or wing passage bulkheads, are further subdivided transversely in a perfectly watertight manner, by numerous complete and partial thwart-ship bulkheads.

The *Warrior* was not provided with a complete double bottom, probably because the longitudinals were not deep enough to have allowed of access to the closed spaces that would have been formed between the two skins. The upper and main decks were completely plated and supported on transverse iron deck beams.

All the earlier ironclads were constructed in a manner very similar to the *Warrior*. The first important improvement was introduced by Sir Edward Reed, when Chief Constructor of the Navy, in the design of H.M.S. *Bellerophon*, the structure of which is illustrated in Fig. 74. In this vessel it was determined to secure the great advantages of a complete

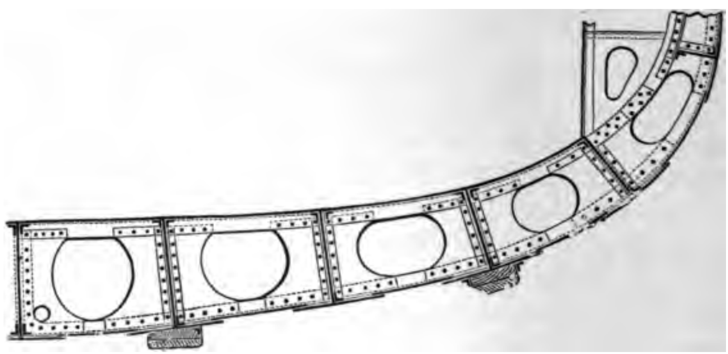


FIG. 74.—Bottom of H.M.S. *Bellerophon*. Commenced 1863.

double bottom, similar to that of the *Great Eastern*, for about two-thirds of the ship's length. In order to make the compartments in the bottom roomy and easily accessible for painting and repair, it was necessary to make the longitudinals much deeper than in the earlier ships. There are six of them

on either side of the keel. They are lightened by holes cut 2 ft. by 1 ft. between each transverse frame, except in those cases where the longitudinal is used to form a watertight compartment. They are secured to the outer bottom by single angle irons continuous throughout the ship's length, and to the inner bottom by short lengths of double angle iron worked in between the transverse frames.

The solid-plate frames of the transverse framing of the *Warrior* are done away with, except at intervals of about 20 ft., where solid plates are required to make watertight subdivisions in the bottom. Otherwise the transverse framing consists of continuous angle irons from gunwale to gunwale, worked on the inner side of the ship and on the under side of the inner bottom, and bracket plates instead of solid frame plates. The bracket plates are attached to the outer bottom by means of short lengths of frame angle irons worked between the longitudinals. They are also, of course, attached to the longitudinals by short lengths of angle iron. These frames are spaced about 4 ft. apart, and there are no intermediate frames.

This arrangement is a great improvement on the structure of the *Warrior* from many points of view. Firstly, the increased depth of the longitudinals and the existence of a double skin add greatly to the power of the vessel to resist bending strains. Secondly, the security of the ship against foundering, in the case of the outer skin being laid open to the sea, is enormously increased by the inner skin and by the subdivision of the space between the two bottoms into water tight compartments. Thirdly, it is an easier and cheaper system to build; and fourthly, it permits water ballast to be used, and thus enables the officer in command to alter the depth of immersion and the trim of his vessel.

In other respects the structure of the *Bellerophon* so nearly resembles that of the *Warrior* that it is unnecessary to describe

its details. This arrangement of the double bottom has been generally adopted in the construction of ships of war, both for our own and for foreign navies.

We may now revert to the mercantile marine, and show how the longitudinal system of construction with a double bottom was re-introduced because of its adaptability for use with water-ballast. The ordinary method of ballasting ships was both inconvenient and expensive. Mr. B. Martell, late Chief Surveyor of Lloyd's Registry, has described what the expense was in the case of a sailing collier trading between the Tyne and the Thames,* and carrying from 250 to 400 tons of coal. A vessel of this type, after discharging her cargo, had to pay 1*s.* per ton to the Trinity lighters for ballast, and 6*d.* per ton for putting it on board. On returning to the loading port another 1*s.* per ton of ballast had to be paid to the River Commissioners, and an additional 10*d.* per ton for depositing it on the river side, thus making total charges of 3*s.* 4*d.* per ton of ballast per round voyage, without reckoning the great loss of time involved in loading and unloading it. For steam colliers, which made many voyages in the year, the introduction of water ballast was a prime necessity; it is therefore not surprising that it was in this type of vessel that the innovation was first introduced. In the year 1852, a screw collier named the *John Bowes* was built at Newcastle, and fitted with temporary appliances for carrying water ballast. These answered so well that a vessel called the *Samuel Laing*, of 609 tons register, was built by Messrs. Palmer at Jarrow, in the year 1854, and fitted with permanent iron ballast tanks laid along the floor plates. A cross section of these tanks is shown in Fig. 75, from which it can be seen that they formed no part of the structure of the ship. This was an obvious

* Paper on "Water Ballast," by Mr. B. Martell, *Transactions, Institution of Naval Architects*, vol. xviii. p. 336.

defect, for it is evident that the tanks lent themselves very readily to being made part of the structure, and might have contributed very materially to the strength of the bottom. The tops of the tanks, for instance, could easily have been converted into an inner bottom. This defect was remedied by the same builders in their next screw collier, the *Rouen*, in which the tanks formed an integral part of the structure of the vessel.

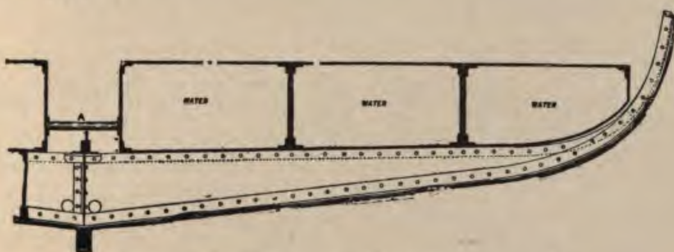


FIG. 75.—Water ballast tanks of the *Samuel Laing*. 1854.

Once the system had taken root in screw colliers, it was gradually introduced into other vessels trading in European waters, and finally into most merchant steamers. The late Mr. Martell gave an example of the financial benefits of this system as applied to a steamer built for the Mediterranean trade and making four voyages a year. The vessel in question, which cost about £20,000 in the year 1877, would have required about 200 tons of ballast. The total cost of obtaining this, of putting it on board, of discharging and of detention during the time of obtaining and unloading the vessel, would often amount to £260 per round voyage; or to, say, £1,000 per annum, equal to an outlay of 5 per cent. per annum on the original cost of the steamer. Many other examples might be quoted of the costliness and inconvenience of the use of the old system of ballast.

It may be here noted that the use of watertanks and double

bottoms in merchant ships was retarded for some years by the great prejudice which existed against them for a time, owing to the number of vessels so fitted that were lost during the years 1872-73. Most of these vessels were grain-laden, and imperfectly provided with contrivances for preventing the cargo from shifting, and it was probably due to this circumstance that the ships were lost. At the same time it is true that many of them were deficient in stability, when carrying homogeneous cargoes like grain or coal, owing to the fact that the inner skin was often fitted at too great a height above the outer bottom, thus unduly raising the position of the centre of gravity of the cargo, while no addition was made to the breadth of the beam. When, however, the causes of these losses were properly understood, the way was prepared for the almost universal adoption of the double bottom, with its attendant advantage of the use of water ballast.

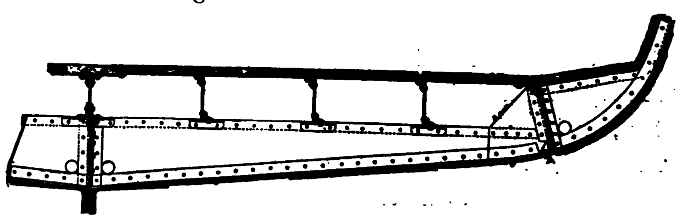


FIG. 76.—McIntyre's water ballast arrangements.

The earliest system which came to be commonly used is illustrated in Fig. 76. It is called the McIntyre plan, after the name of its inventor. The side of the tank is formed by the flange plate A. A series of longitudinals is fitted across the floor plates, and to the tops of these longitudinals is fitted the inner bottom. Many variations and modifications of this plan were adopted from time to time. They were not, however, very satisfactory examples of ship structure, as the tanks, though contributing to the strength of the bottom, were also considerable additions to the weight and cost of the

ship. Moreover, the strength added was superfluous in many cases. This fact, however, enabled the builders to fit the tanks, not necessarily over the whole ship, but at any portion where they might be required, for the purposes of ballasting and trimming. Consequently, we find instances in which the arrangement was fitted either in the fore-hold, or in the after-hold—but not in the engine and boiler space—as well as examples in which it was applied over the whole bottom of the ship.

One or two examples are found in iron ships, built at a comparatively early period, with double bottoms, in which the longitudinals are carried down to the outer bottom. Notably may be mentioned the screw steamers *Scio* and *Assyria*, built by Messrs. Westerman near Genoa in 1874. In these vessels, however, the side longitudinals are not continuous, but are fitted intercostally between the frame plates.

In the year 1876 a vessel named the *Fenton*, of 784 tons gross, was built at Sunderland by Messrs. Hunter & Austin. The bottom of this ship was designed in collaboration with Lloyd's Register of Shipping, and it may be considered as having inaugurated the modern system of constructing merchant ships. The structural arrangements are shown in Fig. 77, the upper part of which is a plan of the bottom, while the lower part is an elevation of one of the transverse members. The longitudinals, which are about 4 ft. apart, are fitted to the bottom of the ship. The transverse frames with the reverse frames are spaced 21 in. apart, and the former run through the longitudinals. At every eighth frame space transverse solid floor-plates (shown at AA) are fitted intercostally between the longitudinals, and form watertight compartments or tanks. Midway between these are bracket plates shown at BB. Intermediately between these and the solid frame plates AA are

angle irons CC for stiffening the longitudinals and the inner bottom.

This vessel was perfectly successful. The system was taken up by Messrs. Denny, of Dumbarton, with great energy, and was applied by them to the *Chilka* and *Chupra* class of 2,000 tons register, built for the British India Steam Navigation Company in 1878. In these vessels bracket-frames were

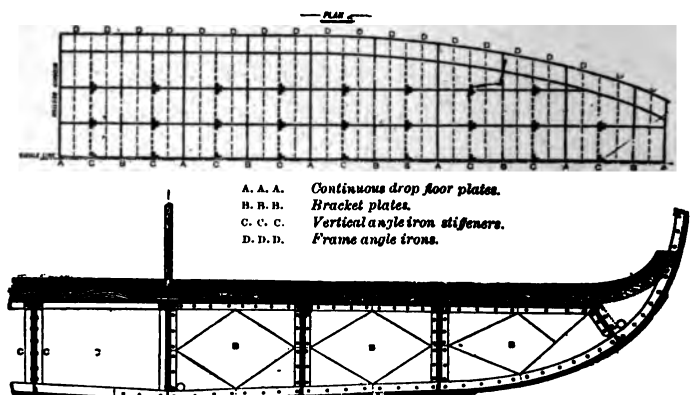


FIG. 77.—Water ballast arrangements of the *Fenton*. 1876.

introduced at every alternate frame in order to secure greater transverse and local strength. As a general rule, bracket-plates are now fitted at every alternate frame in large vessels, and solid-plate frames are introduced at the transverse bulk-heads, under the engines, shaft bearers, thrust blocks, etc.

The chief distinction between the system as applied to war and merchant ships is that, in the former, generally, the reverse frame is continuous, and the frame proper worked in short lengths between the longitudinals, whereas in the mercantile marine the opposite system prevails, the frame proper running through the longitudinals.

Once the system of double bottoms and longitudinal stringers with bracket-plate floors had been introduced in association

Fig. 78.—View of keel ot *Carmania* during construction.

with water-ballast tanks, other features of the longitudinal system of construction, as practised in the Royal Navy, were not slow in finding their way into the structure of merchant ships. For instance, we find that in the *Fenton*, referred to above, partial bulkheads, or deep-web frames as they are now generally called, were introduced into the hold as a substitute for hold-beams. They were made continuous, and side longitudinals were fitted intercostally between them. Examples of this practice have been shown. Where the web frames and side longitudinals intersected, they were connected by diamond plates, similar to those used in the *Annette* (Fig. 72). The web frames were connected to deep deck beams, and were also securely strapped to the inner bottom; and in continuation of them, between the two bottoms, there were solid-plate frames instead of bracket frames. They were spaced from 16 ft. to 20 ft. apart.

Though this system of shipbuilding, as introduced into the mercantile marine in the *Fenton*, and afterwards developed by Messrs. Denny, was not originally adopted for purposes of structural strength, nevertheless, as the size of steamers increased, it rapidly became indispensable as a means of coping with the longitudinal stresses and is now generally adopted in all first-class work. The system is susceptible of many variations in detail in order to meet special requirements. It is not necessary in a work of this character to go into all these variations and modifications, but a description of the application of the system to the Cunard steamer *Carmania*, a Transatlantic liner of the largest size (*see also* pages 93 and 94), will be useful to students.

The central continuous girder of the double bottom (Fig. 78) consists of a flat keel built up of three thicknesses of 1-inch plates, 55 in. wide, riveted together. The web of the girder is 5 ft. deep and 1 in. in thickness. The top

flange is formed of the plates of the inner bottom and heavy angle irons. The floor plates, or transverse girders (Fig. 79), branching out from the central girder are nearly 5 ft. deep, and between them are fitted intercostally (*i.e.* not continuously), six longitudinals, viz., three on each side of the centre. The fourth longitudinal on each side is a continuous girder fore and aft, as also is the margin plate which bounds the double bottom on each side. Between the fourth girder and the margin plate, the continuations of the floor plates are fitted intercostally and a fifth longitudinal is fitted intercostally between these floor plates, about midway between the fourth longitudinal and the margin plate. Most of these features are clearly visible in Fig. 79. Underneath the fifth longitudinals on the outside of the hull are fitted continuous bilge keels. In this way an immensely strong double bottom is formed which serves as a foundation on which the rest of the ship is built.

The side framing, Fig. 80, consists of rolled steel girders of channel section 9 in. deep, spaced 32 in. apart over the greater part of the body of the ship. At the bow and stern the frames are spaced 27 in. apart and are built up of heavy angle irons and reverse angles. Every fifth frame in the boiler and engine rooms, and every sixth frame forward and aft of these spaces is a partial bulkhead, or web frame. The webs of these frames are 30 in. deep and ½ in. thick. They are fastened to the skin of the ship by double angle irons, and their inner edges are strengthened with single angle irons. The flat surfaces of the bow are specially strengthened. The web frames are lightened in the forward and after portions of the hull by cutting circular holes in the plates. Similar holes are also cut in the floor plates and intercostal longitudinal girders for purposes of communication between the various parts of the double bottom. The web

Fig. 79 —View of the double bottom of the *Carmania* during construction.

frames are carried up to the main deck and the channel frames to the bridge-deck amidships and to the weather-deck forward and aft. The channel ribs are connected to the margin plate of the double bottom by means of deep triangular brackets.

The strength is further increased by two fore and aft girders on either side of the ship, in the hold space between the margin plate and the lower deck plating. They are worked intercostally between the web frames. Above the hold the stringers and plating of the various decks give the necessary longitudinal strength. All these details are clearly visible in the illustration, Fig. 80.

There are twelve watertight bulkheads, formed of ½ in. plating, stiffened by 10-in. channel ribs, reaching up to the lower deck and spaced 30 in. apart. These ribs are connected by means of brackets to the inner bottom plating and lower deck. Above the latter the bulkheads are stiffened by means of angle irons and flanges in the plating. All the bulkhead doors can be closed simultaneously from the bridge by means of ingenious hydraulic mechanism.

The deck beams are of channel section connected to the transverse frames by knee brackets. The pillars which support the decks and also tie them to each other are of circular section and vary, according to the work they have to do, from 3 in. to 6 in. diameter. The deck plating is generally ⅝ in. thick, but the stringer plates are 1 in. thick and are doubled over considerable lengths of the main deck.

The shell plating of the hull is generally 1 in. thick. The strakes are about 5 ft. wide. They are lap butted and quadruple riveted. The four top strakes are double strapped and quadruple riveted. The plating of the inner bottom is ¾ in. thick. The outer shell plating of the double bottom is double riveted and the plating of the inner bottom is double strapped and treble riveted.

A comparison of this description with that given of the *Great Eastern* on pages 150 to 157 shows how widely the structural arrangements of the two ships differ. Though the *Great Eastern* was the larger ship of the two and was built of relatively small iron plates, the weight of material used in her structure is stated to have been 10,000 tons as against 12,000 in the case of the *Carmania.*

The structure of certain modern types of cargo vessels such as "Turret," steamers, cantilever framed steamers, and tank oil steamers, has been explained in Chapter VI.

Fig. 80.—View of interior of *Carmania* during construction.

APPENDIX I.

THE EXTERNAL FORCES WHICH ACT ON SHIPS AND THE STRAINS WHICH THEY PRODUCE.

There are two principal categories of general, as distinguished from local, external forces acting on ships, viz. :—

(1) Those which tend to alter the form of the structure in the direction of its length, and which consequently produce longitudinal bending strains, sometimes called "hogging" and "sagging" strains.

(2) Those which tend to deform the structure transversely.

We will commence by considering the simplest case of longitudinal bending stresses, viz., those undergone by a ship when floating at rest in smooth water.

The manner in which the longitudinal bending forces are estimated is as follows :—

The ship is supposed to be divided up into a number of transverse vertical divisions by a series of equidistant vertical planes, as shown in Fig. 81. The weight of the portion between each two adjacent planes

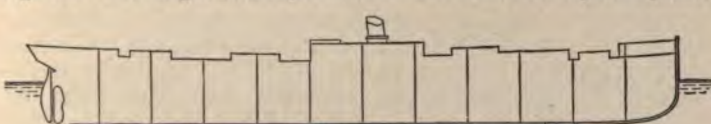


FIG. 81.

is carefully calculated, as also is the weight of cargo and other loads contained in each such part of the ship. Next, the displacement of each separate division is computed. The weights, of course, act vertically downwards, and the weight of the displaced water, *i.e.*, the buoyancy of the division under consideration, acts vertically upwards. Now, considering the ship as a whole, the primary conditions for flotation in a state of rest are, that the weight of the ship acting downwards exactly equals the weight of the displaced water acting upwards, and the centre of effort of the latter, *i.e.*, the centre of buoyancy, must be in the same vertical straight line as the centre of gravity of the

vessel and cargo. But this condition, which is true of the vessel as a whole, is by no means necessarily true of the separate transverse divisions now under consideration. If the condition held for each of any number of divisions into which the vessel could be divided, the latter would not undergo any longitudinal strains whatever, when floating in still water, except those due to longitudinal fluid pressure, and these latter are of a comparatively trifling character. The vessel, in fact, might be likened to a girder resting throughout its whole length on a solid foundation. It would be what is commonly called water-borne throughout, and such a condition of things may be represented by the case of a floating box with thin sides and filled with homogeneous cargo.

In practice the weights and buoyancy are often very unevenly distributed throughout a vessel's length. Take, for instance, the case of an ironclad, with fine ends and heavy armour-plating round the bows and stern. On account of the small displacement of the fine ends and the heavy mass of the armour, the weights acting downwards at these parts considerably preponderate over the buoyancy. In the middle of the ship an opposite condition of things may prevail: the buoyancy of the fuller sections may be so large as to exceed considerably the weights. A ship in this condition would resemble a beam, or girder, supported under its centre and loaded at each end. It would naturally tend to "hog."

The opposite condition of things, viz., a ship in still water resembling a beam supported at the ends and loaded in the middle, is hardly ever met with in practice, because the ends are generally so fine that the buoyancy is not in excess of the weights. It may, however, very easily happen that both in the centre and at the ends the weights are in excess of the buoyancy. Whenever this is the case it follows, from the primary condition of flotation, that at some intermediate positions, between the ends and the centre, the buoyancy must be in excess, and the ship then resembles a beam supported at two points between the ends and the centre, that is so say, the ends overhang the supports, and the structure is loaded in three places, viz., at each end and in the centre. A beam so loaded would undergo hogging, or sagging, *at its centre*, according as the weights at the centre, or at the ends, predominated. In the case of a ship the central weights would generally largely predominate over those at the ends, and the central section between the supports would tend to droop or sag, but the portion over the supports could not sag; on the other hand the ends, under the action of the unsupported loads, would tend to droop, and the whole beam would tend to assume a sinuous form, as shown in Fig. 82.

In the example just given the buoyancy is in excess of the weights over two portions of the length of the ship, while the weight preponderates over three portions. Many more complex cases occur in

practice, especially in warships, which often have concentrated loads, such as armoured turrets and heavy guns, occupying relatively small portions of the length of the ship, while between these positions the loads may be comparatively slight. Cases are known in which the weights preponderate over five sections of the ship and the buoyancy is in excess over four.

It is a matter of importance for the naval architect to investigate systematically the conditions of distribution of weight relatively to buoyancy in all classes of ships which he may have to design, in order that he may provide sufficient strength to meet the longitudinal

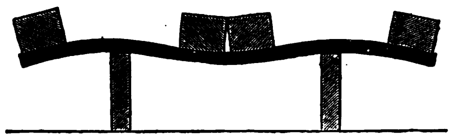


FIG. 82.

stresses resulting from such distribution. The investigation is usually exhibited graphically in the following manner:—A base-line AB (Fig. 83) is drawn, along which the length of the ship to scale is marked off. This length is divided into a number of equal sections corresponding to the number of transverse vertical divisions into which the ship is supposed to be cut up for the purpose of investigation. From the centre of each of these sections an ordinate is drawn vertically upwards. The displacement of each section of the ship in

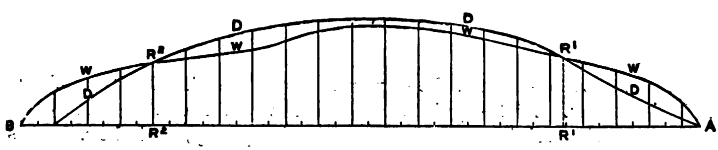


FIG. 83.

tons is then calculated, and marked off to scale on the corresponding ordinate, and a curved line DDD drawn through the points thus obtained. This line is called the "curve of buoyancy," and if the length of the ship, over all, be greater than its length on the water line, the curve of buoyancy will intersect the base-line at points corresponding to the length of the water-line. The weights of hull, fittings, cargo, coal, stores, etc., are then treated in a similar fashion for each section of the ship, and lengths corresponding to these weights in tons, to the same scale as before, are set off on the ordinates corresponding

to the sections, and another curve WWW drawn through these. This line is called the "curve of weights." To estimate exactly the weights of each section, is, of course, a long and tedious task. If the work has been correctly carried out, the area bounded by the base-line and the curve DDD exactly equals the corresponding area bounded by the curve WWW, and the centre of gravity of the two areas is in the same vertical straight line. This, of course, follows from the conditions of flotation previously stated.

These two curves show at a glance the relative distributions of the weights and buoyancy. Where the curve DDD lies outside the curve WWW the buoyancy is in excess by the amount of the intercept between the two curves, and whenever it falls within WWW the weights are in excess by the amount of the intercept, and the areas of the portions intercepted between the two curves which show the buoyancy

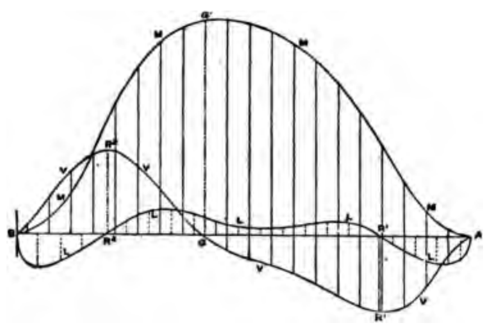


FIG. 84.

to be in excess must equal the corresponding areas showing the weights to be in excess. At the points R_1 and R^2 where the two curves cross each other the weight exactly equals the buoyancy, and the vessel is there said to be water-borne.

Fig. 83 represents the case of the old ironclad H.M.S. *Minotaur*, in which the weights preponderate at the ends of the vessel and the buoyancy at the middle.

It is usual to deduce from the curves of buoyancy and weight another and simpler curve in the following manner. We will again take the case of the *Minotaur*. The same base-line and ordinates are drawn, but for convenience sake to a different scale, and on each ordinate a portion is marked off (Fig. 84) equal to the intercept between the two curves in Fig. 83. When the weight is in excess this portion is marked off on the ordinate *below* the base line,

and when the buoyancy is in excess it is marked off *above* the base line, and in this way a new curved line LLL is obtained, called the "curve of loads."

Having thus shown how the forces which produce the longitudinal strains on the ship in still water are estimated and represented, the next step is to show the effect of the forces on the ship, that is to say, to show what portions of the ship are subjected to "hogging" and what portions to "sagging" stresses, and to what extent in each case. In order to do this graphically, a curve of bending moments is deduced from the curve of loads. This curve MMM is such that the vertical ordinate at a point corresponding to any section of the ship is proportioned to the bending moment at that section. The bending moment at any point is defined to be the product of the resultant of all the forces acting between the point in question and either of the ends of the ship, multiplied by the perpendicular distance from the point to the line of action of the resultant. Hence, to find the ordinate at any point on the base line we must multiply each of the net forces acting downwards (*i.e.*, the preponderance of weights over buoyancy) by the perpendicular distances from the point to their lines of action and add the products together, and repeat the operation for the net forces acting upwards; the difference between the two products is proportional to the ordinate of the curve of bending moments for the point in question, and must be set off upwards, or downwards, according as the resultant moment of the forces tends to bend the ship at the given point upwards or downwards. Hogging moments are represented by the ordinates of the curve above the base-line and sagging moments by those below. The best practical method of drawing the curve of bending moments from the curve of loads, is to take the centre of gravity of each of the areas bounded by the base-line and the separate loops of this curve above and below that line; we can then easily measure the distance from the point about which the moments are taken to the vertical line passing through the centre of gravity of each area. This distance measures the arm of the moment, and the area of the space bounded by each loop and the base-line is proportional to the amount of the forces acting upwards, or downwards.

In Fig. 84 MMM represents the curve of bending moments for the same ship (the old *Minotaur*), the curve of loads of which is represented by LLL.

In addition to the bending moments due to the vertical forces, an additional moment due to the fluid pressures acting horizontally fore and aft has to be considered. These pressures tend to compress the immersed portion of the hull, and may be supposed to be concentrated at the centre of pressure of the immersed part of the midship section. The addition to the bending moments due to the fluid pressure is often considerable in the cases of ships floating in still water,

but it is neglected in practice because the strains for still water do not regulate the strength of the structure, and the amount of the fluid pressure moments is small compared to those which are due to the vertical forces when a vessel is crossing waves of about her own length.

The general character of the curve of bending moments *in still water* varies considerably in different ships according to the relative distribution of the weights and buoyancy. In the great majority of such cases only hogging moments are experienced. In ships which are heavily loaded at the extremities, like H.M.S. *Minotaur*, and the weight throughout the remainder of the length fairly evenly distributed, the hogging moments amidships are often excessive. Nearly all vessels have some preponderance of weight at the ends, owing to the relative fineness of the form at these parts, but many have in addition excesses of weight amidships, and it might be thought at first that, in such cases, sagging strains would be experienced over the central portions. It must, however, be borne in mind that in these cases there must be very considerable portions of the hull between the centre

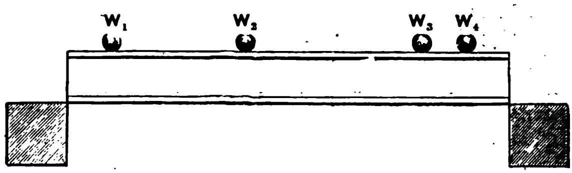


FIG. 85.

and the ends in which the buoyancy predominates, and that unless there is a very large preponderance of weight amidships, sagging strains will not be experienced there in still water, though the hogging moments will be greatly reduced as compared with those which prevail in ships of the *Minotaur* class. Merchant vessels of the type described on page 110, when heavily laden with metal cargo concentrated on either side of the engine and boiler spaces, are occasionally found to experience sagging strains, even in still water.

Before leaving this part of the subject, attention must be called to the fact that the state of stress of a laden ship in still water at the commencement of her voyage differs very materially from the corresponding state at the end of a voyage, when the weights amidships have been seriously diminished by the consumption of bunker coal. The effect of this reduction, if not compensated for, is to considerably increase the hogging moments.

The longitudinal bending strains are not the only effects produced

by the distribution of weight and buoyancy. A totally different class of vertical strains, called shearing or racking strains, is also produced. The word "shearing" is used, because the tendency of these strains is to sever, or shear, the vessel in vertical planes, in a manner similar to that in which metal is cut by the action of machine shears. The shearing force at any vertical transverse section is the resultant force, upward or downward, at that section, of all the vertical forces acting between it and either end of the vessel.

The nature of this force may perhaps best be understood by considering a simple case of the shearing strain of a girder, supported at each end, as in Fig. 85. In this case it will be obvious that the resultant of the vertical forces, acting on any transverse section of the girder, varies with the position of the section relatively to the weights. For instance, neglecting the weight of the girder itself, between the left abutment and the first weight the shearing force equals the reaction of the abutment acting upwards. In any section between the first and second weights, the shearing force equals the reaction in the abutment, minus the first weight. In any section between the second and third weight, the shearing force equals the reaction in the same abutment, minus the two first weights, and so on.

In the case of the ship, the shearing force is easily represented at any point by means of the ordinates of a curve VVV readily derived from the curve of loads LLL in the following manner. At any point *a* on the base line (Fig. 84) an ordinate is erected, the length of which is determined as follows. First take the areas of any space, or spaces, enclosed by the curve of loads below the base line, between the point and either end of the line, and add them together; in this case there is one such area, viz., BLR $_2$ between the point *a* and the end B; next perform a similar operation for any space, or spaces, enclosed by the curve of loads above the base line between the same points; in this case there is one such area, viz., R^2aL. The difference between the two areas thus obtained will give the resultant upward or downward force, in this particular instance equal to zero, and the length of the ordinate must be drawn to scale, proportioned to th area thus obtained. Similarly ordinates may be drawn at any number of stations, and through their ends the curve VVV is drawn, called the "curve of shearing forces."

Whenever the curve VVV crosses the base line there is no shearing force, that is to say, the resultant of the upward and downward forces on each of the segments into which such a point divides the base line equals zero; therefore each such segment is separately waterborne, and the points of no shearing are called "sections of water-borne divisions" of the ship. They are situated under the points where the ordinates of the loops of the curve of bending moments attain a maximum or a minimum value. For instance B, *a*, A, are such points in Fig. 84.

The ordinates of the loops of the curve of shearing force attain their maximum value over those points, R^1, and R^2, where the curve of loads crosses the base line.

We have so far considered the general character of the principal longitudinal and vertical stresses to which a ship is subjected in still water, but nothing has been said regarding the manner in which the material of the vessel is arranged, in order to meet them. The consideration of this subject must, however, be postponed till we have considered the effect upon the stresses caused by waves crossing the vessel at right angles. It is usual in investigating this subject to consider only the cases of waves of about the same length as the vessel, the

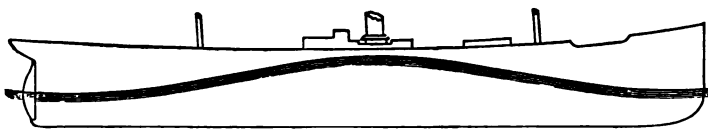


FIG. 86.

length of the waves being measured from crest to crest, or from centre to centre of the hollow. The height of a simple wave from hollow to crest for a given wave length is known, as also is the outline of the section of the wave, hence the effect of the passage of the wave upon the distribution of the buoyancy can be approximately calculated A mere inspection of Figs. 86 and 87 will show what an enormous difference the passage of such a wave makes on the distribution of

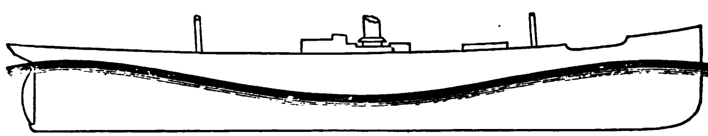


FIG. 87.

the buoyancy. When the crest of the wave is under the middle of the ship, the water at that part rises much higher than the normal plane of flotation, greatly increasing the buoyancy at the middle of the hull; while, on the other hand, at the bow and stern, which are in the hollows of the wave, the buoyancy is greatly diminished, and the general tendency is, of course, to increase the hogging moments throughout the length of the vessel. Fig. 87 shows the reverse state of things; the hollow being under the middle of the ship, the buoyancy there is consequently diminished, while the two ends are deeply immersed in the crests of the waves, and the buoyancy correspondingly

increased, with the result that hogging moments must not only be diminished, but in many cases sagging moments are substituted for them.

The methods of drawing the curves of weight, buoyancy, loads, bending moments, and shearing forces for vessels crossing waves are

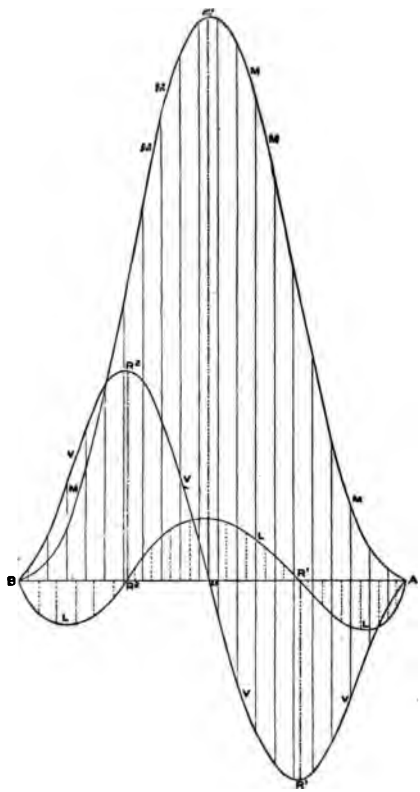


FIG. 88

precisely similar in principle to those used for drawing the corresponding curves in still water. The difference arises solely in the distribution of the buoyancy. It is not pretended that such calculations are strictly accurate, because the method takes no account of many of the complex elements of the case, but, nevertheless, they are of very great

value as showing what the various strains approximate to, and also for the purpose of comparing the strains of ships of various types and laden in different ways.

To show the enormous effect caused by the passage of waves, a graphic diagram is given in Fig. 88 of the curve of loads, bending moments and shearing forces in the case of the *Minotaur* when poised on the crest of a wave 400 ft. long and 25 ft. high. Fig. 89 gives the corresponding curves when the hollow of the same wave passes under the centre of the ship. These may be compared with the corresponding diagram (Fig. 84) on page 174.

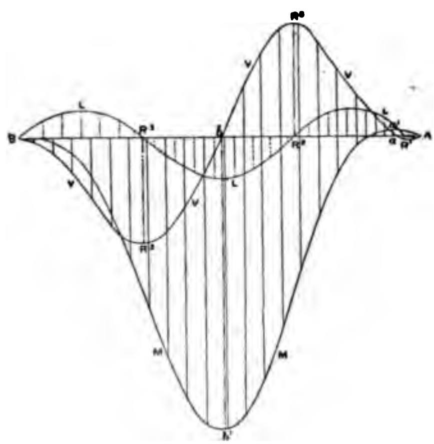


FIG. 89.

The annexed table also shows the variations in the bending moments for several ships, taken under three conditions, viz., in still water, poised on the crest of a wave of the length of each ship, and riding across the hollow of a similar wave.

For the purpose of comparison between ships of different sizes, the bending moments are given as a fraction of the length of the ship, in feet, multiplied by the displacement in tons, and as the latter data for each ship are given in separate columns the actual bending moment in each case can be obtained in foot tons by multiplying together the fraction, the length, and the displacement. It should here be noted that the maximum bending moments on the crest of waves are all hogging, while across the hollow of the wave they are all sagging. The *Minotaur* and *Victoria and Albert* are the old vessels of these names.

Name of Ship.	Length in feet.	Weight or Displacement in tons.	Maximum bending moments expressed as a fraction of length multiplied by weight.		
			Still water.	Crest of wave. +	Hollow of wave. −
Minotaur	400	10690	$\frac{1}{88}$	$\frac{1}{28}$	$\frac{1}{53}$
Victoria and Albert	300	2000	$\frac{1}{139}$	$\frac{1}{43}$	$\frac{1}{23}$
Devastation ..	285	9330	$\frac{1}{70}$	$\frac{1}{71}$	$\frac{1}{151}$
Bellerophon ..	300	7550	$\frac{1}{176}$	$\frac{1}{48 \cdot 5}$	$\frac{1}{43}$
Well-decker, with homogeneous cargo	290	4940	$\frac{1}{238}$	$\frac{1}{37}$	$\frac{1}{38}$
Well-decker, with iron ore cargo ..	290	4940	...	$\frac{1}{120}$	$\frac{1}{21}$
Mary	210	442	$\frac{1}{71}$	$\frac{1}{37}$	$\frac{1}{17 \cdot 4}$

A comparison of the fractions given in this table is most instructive. We see that in extreme cases, such as that of the well-decker with homogeneous cargo, the maximum hogging moment when the vessel is crossing waves of her own length is more than six times as great as the corresponding moment for still water. We may also notice that vessels like the *Minotaur*, which are very heavily laden at the ends, undergo very severe hogging moments when on the crest of the wave. In the case of this vessel in the latter position the moment is no less than one twenty-eighth of the displacement, multiplied by the length. On the other hand, a vessel of this type gains distinctly when she rides on the hollow of the wave, the maximum sagging moment being only about one-half of the corresponding hogging moment. Compare this with the well-decker laden with iron ore, chiefly concentrated fore and aft of the engine and boiler space. In this case the sagging moment, when the vessel is across the hollow, is about six times greater than the hogging moment when on the crest. The fact has already been mentioned that, when crossed by waves of their own length, vessels experience sagging and bending moments which alternate with great rapidity. In the case of the *Minotaur* this occurred thirteen times per minute, while in that of the well-decker mentioned in the table it occurs sixteen times per minute.

The case of the *Mary*, the last vessel given in the table, is particularly instructive. It will be noticed that the sagging moment on the hollow of the wave is as much as one-seventeenth of the length multiplied by the displacement. This vessel was very shallow, having been intended for river navigation. Her dimensions were, length 210 ft., beam 25 ft., moulded depth only 8 ft. 6 in. We shall see hereafter that the effect of a

bending moment in straining the material of which the vessel is built diminishes as the depth increases. Now this vessel having been shallow, and having experienced very severe sagging moments, was strained beyond the powers of endurance of the metal, and broke in two when proceeding by sea to her destination. (*See also* page 202.)

A particularly instructive series of diagrams is given in Figs. 90 to 93, illustrating the curves of weights, WWW ; buoyancy or displacement, DDD ; loads; LLL ; bending moments, MMM ; shearing force, VVV ; for the well-decker referred to in the preceding table, the two latter curves having been computed—under the following conditions, viz.—

(1) The ship and bunker empty, in still water (Fig. 90).

(2) The ship fully laden with a light homogeneous cargo filling all available spaces and bunkers full, in still water (Fig. 91).

(3) The ship laden with homogeneous cargo and bunkers full, on a wave-crest (Fig. 92).

(4) The ship laden with homogeneous cargo and bunkers full, on a wave-hollow (Fig. 93).*

In the foregoing investigations no account has been taken of the stresses, due to the raising, or lowering, of the vessel relatively to the normal plane of flotation by the action of the waves, nor yet to the effect of rolling, pitching, scending, and yawing, all of which motions must, to some extent, modify the amounts of the strains experienced. To completely represent the effects of these disturbing causes by any mathematical calculation would be very difficult, because the conditions to be taken into account are so numerous and complicated.†

We must next briefly consider the nature of the transverse stresses on ships, that is to say, those which tend to deform the shape of any transverse section of a vessel. These stresses are most severe when a vessel is in dry dock and supported by blocks under her keel alone, or aground in the upright position. When in dry dock and supported only under the keel a pressure equal to the whole weight of the vessel acts upwards through the central longitudinal plane. This plane divides the vessel into two symmetrical portions, the weight of each of which may be supposed to be concentrated at the centre of gravity of

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* These diagrams and also Figs. 86, 87 and 101 are taken from a paper by Mr. G. Bergström, entitled "On Structural Strength of Cargo Steamers," published in Vol. V. of the *Transactions of the North East Coast Institution of Engineers and Shipbuilders.* (p 133).

† A mathematical treatment of this subject has been published by Captain A. Kriloff, in Vol. XL., the *Transactions of the Institution of Naval Architects*, in two papers, entitled " A General Theory of the Oscillations of a Ship on Waves," and " On Stresses experienced by a Ship in a Sea-way."

each half. The weight of each half, multiplied by the distance of the centre of gravity from the central plane, constitutes a bending moment which tends to force the bottom upwards, and to cause the sides of the vessel to droop at the turn of the bilge. The transverse section of the vessel, in fact, resembles a beam supported under its centre and loaded

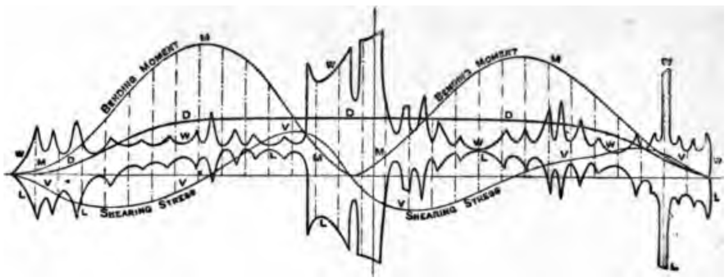

FIG. 90.

near the two ends. The pressure on the keel is transmitted upward through the pillars which support the deck-beams, with the result that these latter and the deck plating are pressed upwards, and consequently are put into a state of tension and render great assistance to the keel,

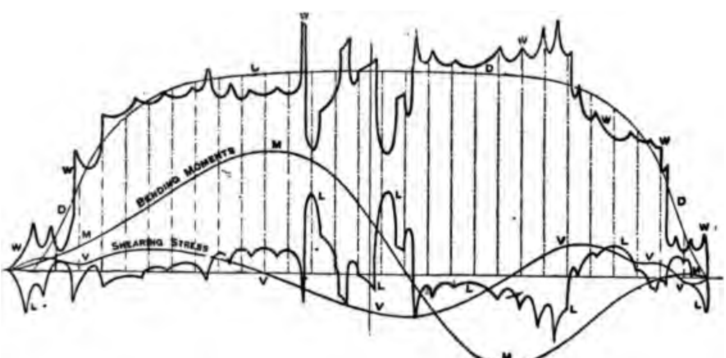

FIG. 91.

the longitudinals, the floors, and bottom plating in resisting the tendency to undergo a change of form.

If a loaded vessel be placed in dry dock, in the manner mentioned, the stresses brought upon the transverse frames are sometimes very severe, and the vessel should always be supported by shores in addition to the keel blocks. If this be effectually carried out, a great part of the

weight is taken off the keel and the transverse bending moment correspondingly reduced. Some vessels, notably American warships, are constructed with docking keels so that they will lie firmly on the blocks in dry dock without shores.

When the ship is afloat in still water the conditions of transverse strain are very different to those experienced when the vessel is supported under the keel alone in dry dock. When afloat the central support is replaced by the buoyancy of the water acting upwards over the whole of the bottom, and in taking moments about the middle line we have to consider not merely the moment due to the weight and the distance of the centre of gravity of each half from the central vertical plane, but also the moment acting in the opposite direction, due to the buoyancy acting upwards through the centre of buoyancy of each half,

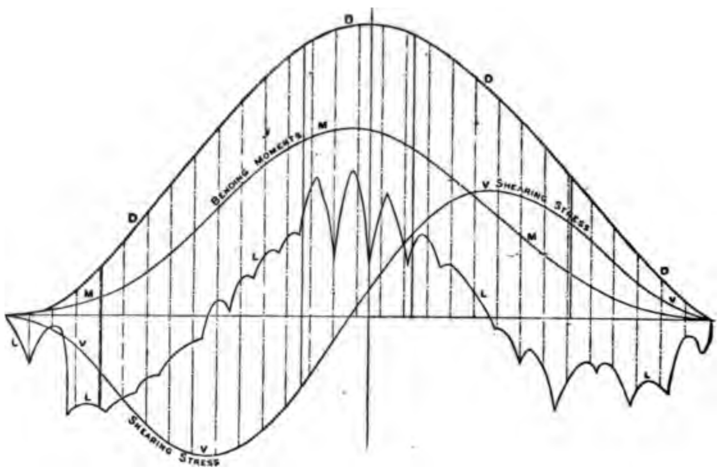

FIG. 92.

multiplied by the distance of the centre of buoyancy from the central vertical plane. Hence the transverse strains of a vessel when afloat will, in general, be far less severe than when in dry dock. The position of the centre of gravity of each half of the vessel, and consequently the amount of the transverse bending moment, will vary considerably according to the distribution of the weights of the cargo. In cases where heavy weights are borne on, or near, the sides, as, for instance, when side armour and heavy broadside guns are carried, the bending moment is greatly increased.

In addition to the foregoing influences the pressure of the water acting on the sides of the vessel tends to collapse the structure, and thus

to bring about changes in the transverse form. The amount of this pressure varies with the depth of the hull plating below the water-line. The centre of horizontal pressure is generally taken to be at about two-thirds of the draft below the load-line. The general form of the hull of a ship is well calculated to resist these horizontal pressures; but, at the ends, where the surfaces are flatter than elsewhere, the pressures are sometimes severely felt unless the skin of the ship is well supported by the internal framework.

When a vessel passes from still water into waves which cause her to roll the transverse strains are considerably increased. The amount of additional strain due to this cause depends largely upon the period and amplitude of the oscillation. The general effect of rolling is to tend to cause distortion of form transversely, the decks tending to

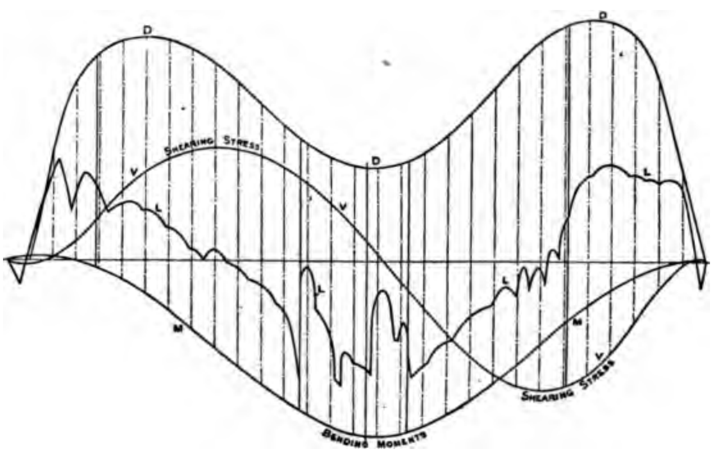

FIG. 93.

alter the angle which, in the normal state, they form with the sides. The angle tends to become more acute than the normal on the side to which the vessel is inclined, and *vice versâ* more obtuse than the normal on the other side. At the bilges corresponding, but opposite, changes tend to take place. This effect has often been noticed in wooden ships when rolling heavily, and is manifested by the way in which the beam knee fastenings work loose.

In the present state of our knowledge and of our powers of analysis it is not possible to estimate the quantitative value of transverse action in the same way that we can the longitudinal bending stresses.

The local stresses which vessels undergo are very numerous and varied in cause and character. It will not be possible here to do more

than enumerate some of the principal amongst them. Reverting to the distribution of the loads and buoyancy which, as we have seen, produces general strains on the ship, it must now be pointed out that a circumscribed, or local, strain may be produced on a portion of the deck, or the side, or bottom, of a ship, by a concentrated load, or even by the buoyancy being greatly in excess of the weights over a limited portion of the hull. As instances of concentrated loads, heavily armoured turrets, armoured bulkheads, side armour, heavy ordnance, engines, boilers and piled up cargo of ore, or metal, may be mentioned. To provide against the local effects of such loads special methods must be adopted of distributing their action over a large area, as otherwise the decks might be deflected, or the bottom bulged outwards, or inwards, according to the direction of the forces. Again, taking the ground may, in addition to the general strains, cause local deflection of the most serious character. The action of the screw propeller causes severe stresses in the neighbourhood of the stern post. The same may be said of the engines when working, especially if the moving parts are not balanced. The thrust block, through which the propelling power of the screw is communicated to the vessel, and also the parts of the vessel to which the thrust block is attached, experience heavy local stresses. Sailing ships also experience local stresses from the action of the masts and rigging. The masts especially, in addition to bearing the stresses due to the pressure of the sails, are often most severely strained by the rapid reversal of their oscillating motion when a vessel rolls violently, and the stresses are communicated to portions of the hull of the ship. The shrouds by which the masts are stayed bring local transverse stresses on the sides of the ship, as will be readily understood when it is borne in mind that the shrouds on one side of a vessel under sail must be in a state of tension. The tensile force can be resolved at the point of attachment into a horizontal and vertical component, the former of which tends to pull in the sides, *i.e.*, to deform the vessel transversely, while the latter sets up in them a direct local tension.

By far the most formidable local stresses to which vessels are subjected are those due to collision. When collision is used as a means of offence, as in the case of warships intended to act as rams, the bows have to be constructed of enormous strength, so as to resist, not only the tendency to be stove in, but also the tendency to be wrenched transversely, which occurs when the vessel struck is crossing the bows of the striker. The bows of merchantmen also are locally strengthened, and the body of the ship immediately behind the bow is fitted with a water-tight bulkhead, called the "collision" bulkhead, intended to confine the water which may be admitted to a small portion of the vessel. Of course, no structure that could possibly be devised in practice would save a vessel from being cut open to the sea when struck

in collision. Hence all structural arrangements intended to meet the effects of such accidents take the form of localising the damage by confining the water to certain portions of the ship. This can only be done effectually by subdividing the vessel, by means of efficiently supported transverse water-tight bulkheads, into compartments of such limited size that if any one of them is laid open to the sea the powers of flotation of the ship will not be compromised.

Having now referred to the principal local and general stresses which ships undergo, we must next consider how the structure of the ship is adapted to resisting the strains produced. The structure of a ship is of a complex character, because many things have to be considered in its design besides the mere distribution of the material for the purpose of resisting the local and general stresses. Hence it will be desirable to commence the consideration of this question by investigating the manner in which a very simple structure, such as a beam of rectangular section, behaves when subjected to bending

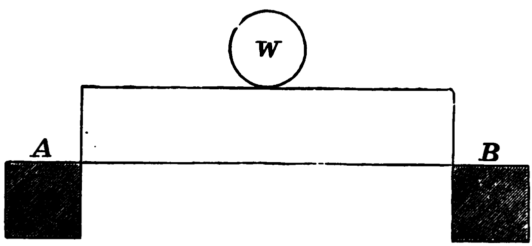

FIG. 94.

stresses. From the results of this investigation we shall be able to draw conclusions as to the best methods of distributing the material in the hull of a ship, so as to obtain the greatest longitudinal structural strength. In Fig. 94 AB represents a homogeneous beam of uniform rectangular section, supported by abutments at the ends A and B, and bearing the load of its own inherent weight and of the added weight W. The beam is therefore acted upon by the upward pressure of the two abutments and the downward pressure of the weights, all acting parallel with one another and in a vertical plane. The effect of those forces acting on the beam is, we know from experience, to deflect it, or bend it into a curved shape, as shown in a very exaggerated form in Fig. 95. The upper surface is shortened, *i.e.* put into compression. The lower surface, on the contrary, is lengthened, or put into tension, while at the centre of the section is a surface, *ab*, of unchanged length which is called the "neutral surface." Between *ab* and the upper surface the whole of the material of the beam is shortened, but

the shortening is not uniform; it increases gradually from the neutral surface, where it is *nil*, to the upper surface, where it is a maximum. Similarly between *ab* and the lower surface the whole of the material is lengthened, the lengthening increasing gradually from *ab* till it reaches a maximum at the lower surface.

If the material of which the beam is made is perfectly elastic, or is not strained beyond its elastic limits, the forces exerted by it in resisting the shortening and lengthening are proportional to the actual amount of shortening and lengthening produced. The expression of this fact, which lies at the root of our knowledge of the behaviour of materials under stress, is known as "Hooke's law of elasticity," and may be stated thus :—When a piece of elastic material is strained, *i.e.*, altered in length by any applied force, the stress, *i.e.*, the reactive force set up in the material, which is equal to the applied force, is proportional to the alteration of length. No materials are perfectly elastic; that is to say, if they be altered in length by the application of a force, they will not, under all circumstances, when the application of the force is discontinued, return to their original length. The materials used in engineering structures, especially iron and steel,

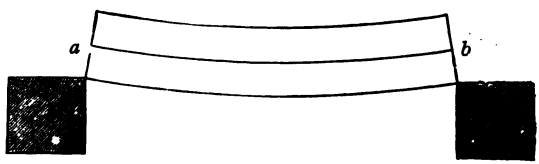

FIG. 95.

are, however, practically, perfectly elastic so long as the strain does not exceed a certain limit; that is to say, so long as the alteration in length, per unit of length, produced in the material by the action of the force is small, these materials will return practically to their original length when the force ceases to act. If, however, the alteration in length, per unit of length, exceeds a certain limit, called the elastic limit, Hooke's law no longer applies, and the alteration in length per unit of length is no longer proportional to the applied force, and when the latter ceases to act the material does not return to its original dimensions, but remains permanently shortened, or lengthened, as the case may be. As, however, engineers choose the dimensions of the separate parts of their structures so that they are never strained beyond the elastic limit, we may, in all that follows, consider the material as if it were perfectly elastic, and may proceed to apply Hooke's law to the investigation of the strains in the material of the beam under consideration.

The curve into which a homogeneous elastic beam of uniform cross-section is bent does not, under ordinary circumstances, differ sensibly from a circular arc, and in the case of deflection under a *uniform* bending moment may be proved to be truly circular. We shall in all that follows assume that the arc is part of a circle. The state of stress of each particle of the beam can then be determined by the simplest and most elementary of geometrical considerations.

Let the radius of the circular arc into which the neutral surface is bent be denoted by R, and the radial distance from the neutral surface to any other point of the beam by y, so that the radius of this point is $R+y$ or $R-y$, according as the point is beyond, or with in, the neutral surface, reckoning from the centre of the arc.

Consider a given length of the material at the neutral surface AB, Fig. 97, and compare it with the length CD, the radius of which is $R+y$. Before bending, AB and CD were of the same length. After bending CD is the longer by the amount CD − AB. The strain in CD is not measured by the absolute alteration in its length from its original condition, but by the alteration in its length per unit of original length $= \frac{CD - AB}{AB} = \frac{CD}{AB} - 1$. Now, CD and AB being circular arcs are proportional to their respective radii. Therefore $\frac{CD}{AB} = \frac{R+y}{R}$. Therefore the strain in CD $= \frac{R+y}{R} - 1 = \frac{y}{R}$.

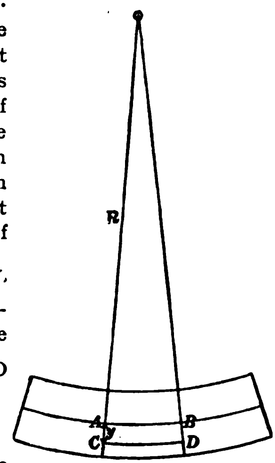

FIG. 96.

This strain is usually denoted by the letter e.

Hence we may say that the strain in any layer of the beam after bending equals the radial distance of that layer from the neutral surface divided by the radius of curvature of the neutral surface, or $e = \frac{y}{R}$.

Now, by Hooke's law the stress of tension, or of compression, is proportional to the strain, or alteration of length, per unit of length. The intensity of stresses is usually estimated as so many pounds per square inch.

Let E be the number of pounds per square inch required to strain the piece of material, supposed to be perfectly elastic, to twice its original length. This quantity is called the "Modulus of Elasticity," and has been experimentally deduced for all materials used in engineering structures.

We can now obtain the following proportion :—

As the tension per square inch (E) required to stretch a unit length of material to twice its original length, is to the elongation produced by this tension (*i.e.* unity), so is the tension (p) per square inch required to produce the elongation e, to the elongation e. Or shortly—

$$E : 1 :: p : e$$

$$\therefore p = Ee = E\frac{y}{R}.$$

Exactly the same reasoning applies to forces of compression.

This is a most important relation, as it enables us to ascertain the tension, or compression, at any point in a beam bent under a load, when we know the radius of its curvature, the exact position of the neutral surface, and the modulus of elasticity of its material. From it we see that the tension, or compression, increases exactly in proportion to the distance from the neutral surface. It therefore becomes absolutely necessary to know how to find the position of the neutral surface for a beam of any cross-section. It will be noted that the above reasoning is altogether independent of the form of the cross-section, so long as that section, whatever its shape, is uniform throughout the whole length of the beam.

The position of the neutral surface can be easily ascertained. As the beam is at rest, the resultant of all the horizontal forces of compression on one side of the neutral axis is equal to and acts parallel, but in the opposite direction, to the resultant of all the forces of tension on the other side of the beam. In other words, the resultant of the two sets of forces is zero.

Now consider the force acting on an indefinitely thin horizontal strip of the cross-section of the beam, the breadth of which in inches right across the section is b, the vertical depth d, and the intensity of the force of tension, or compression, in which is p lbs. per square inch. The total force exerted in this strip equals its area in square inches multiplied by the tension, or compression, per square inch $= p \times b \times d$. The force in the whole section of the beam is the sum of the forces in all the elementary thin horizontal strips into which the section can be divided. The sum is expressed mathematically by the symbol Σ. Hence we can express the total force of compression and tension in the beam by $\Sigma\ (p.\ bd)$. Now p is a quantity which varies with the distance of each strip from the neutral surface, and it has been shown above that

$$p = E\frac{y}{R}$$

where E and R are constant quantities.

Hence the sum total of the forces in the cross-section may be represented by the symbol

$$\frac{E}{R}\Sigma\ y\ .\ bd$$

Also it was shown above that this sum total must equal zero. Hence we obtain the relation

$$\frac{E}{R} \Sigma\, y \,.\, bd = 0$$

$$\therefore\ \Sigma\, y \,.\, bd = 0$$

That is to say, the sum of the products of each elementary strip, multiplied by its distance from the neutral surface, equals zero. Now, we know from elementary statics that this is also the condition which determines the position of a line passing through the centre of gravity of the section. Hence we see that the neutral axis passes through the centre of gravity of the cross-section, a condition which determines its position.

Having ascertained the position of the neutral surface and also the intensity of the stresses of tension and compression at every point of the section, we are now in a position to find the total effect of the cross-section of the beam in resisting the bending action of the external forces.

By the principles of elementary statics we know that the moment of the external forces applied to the beam on one side of any given transverse section, about any point in the section, must equal the moment of the internal stresses of compression and tension about the same point in the section. As the resultants of the forces of compression and tension form a couple, it is immaterial about what point in the section this latter moment is estimated, as it comes out the same for all points ; we will, therefore, select the neutral axis.

To obtain the moment in question, all we have to do is to multiply the internal stress in any elementary horizontal strip reaching across the transverse section of the beam, by the distance of that strip from the neutral axis, and sum up the results for the whole surface of the beam. We have already seen that the stress in any one of these strips is represented by the expression $p \times bd$, or $E\frac{y}{R} \times bd$. Hence the moment of the strip about the neutral axis is represented by the above expression multiplied by y, the distance from the neutral axis ; therefore the moment of any particular strip $= E\frac{y^2}{R} \times bd$, and the total moment of the whole section equals the sum of the results for the separate strips $= \frac{E}{R} \Sigma\, y^2 \times bd$. Calling the moment of the external forces about the same point M, we have, therefore—

$$M = \frac{E}{R} \Sigma\, y^2 \times bd.$$

The expression $\Sigma\, y^2 \times bd$ occurs very frequently in mechanical investigations. It is always called the " moment of inertia," a name, however, which has no relation to the subject under consideration. It is always symbolised by the letter I.

Hence the above equation, written shortly, becomes—

$$M = \frac{E}{R} I.$$

It connects the moment of the external forces with the moment of inertia of the beam about its neutral axis, the modulus of elasticity of the material, and the radius of curvature of the beam as deflected by the load it carries.

We have previously found that p, the stress at any point, the dis tance of which from the neutral axis is y, is given by the equation—

$$\frac{p}{y} = \frac{E}{R}$$

Therefore, substituting this value of $\frac{E}{R}$, we obtain the equation—

$$M = \frac{p}{y} I,$$

which connects the moment of the external forces with the moment of inertia of the section of the beam and the internal stress at any point.

This equation is of great use in solving such questions as the maximum stress produced in any part of a loaded beam. For instance, the problem before engineers is often so to design their structures that, under given conditions of loading, the maximum stress in any part shall not exceed a given fraction, such as one-fourth, or one-fifth, of the breaking stress. Now we know, from what has gone before, that the maximum stress in a loaded beam occurs at its extreme top and bottom fibres. We have, therefore, in the above equation, merely to substitute for p the number of pounds per square inch which is considered a safe stress to put upon the material, and for y the distance of the extreme top, or bottom, layers from the neutral axis.

Before, however, we can apply the equation to solving any questions which may arise concerning the stress in a loaded beam of any cross-section, we must know the value of its moment of inertia, I, about the neutral axis. The calculation of this quantity, analytically, involves a knowledge of the integral calculus and need not here be explained. It will be sufficient for our purpose to give the value of I for the forms of cross-section which occur in the shipbuilder's practice. Nearly every case that occurs may be solved by a knowledge of the value of the moment of inertia for a rectangular section two of the sides of which are horizontal. From this may be derived the value of I for all sections that are made up of rectangles, such as flanged girders and hollow-box girders, two of the sides of which are horizontal. In every such case the value of I is equal to the area of the section, multiplied by the square of its depth, multiplied by a fraction which varies with the form of the section.

Denoting the area by A, and the depth by d, we give the following values for I :—

For a rectangular section, two of the sides being horizontal—

$$I = \frac{Ad^2}{12}.$$

For a triangle with one side horizontal—

$$I = \frac{Ad^2}{18}.$$

With the knowledge of these values we can now proceed to ascertain the stresses set up in a beam of rectangular section, of given dimensions and loaded in a given manner. We will then see how the strength of the beam may be altered by varying the form of the cross-section, and from the results obtained we will draw conclusions as to the effect of the distribution of the material upon the strength of ships.

We will take as an example, a wrought-iron beam four inches wide, six inches deep, and ten feet between its supports, and will find out what load, uniformly distributed over its length, it can carry, on the assumption that the intensity of the maximum stress of either tension, or compression, in any part of the beam shall not exceed five tons per square inch. Let W be the total weight, including that of the beam itself. Let the beam be divided into any two parts which bear to each other the ratio $m : n$ by any vertical transverse plane CD.

Then we have $m + n = l =$ the length of the beam $= 10$ feet. Considering the part of the beam between CD and the right abutment B, we find that this portion is acted upon by the following external forces :—

The reaction of the abutment B acting upwards $= \frac{W}{2}$

The weight between B and CD acting downwards $= W \times \frac{n}{n + m}$.

The shearing force at the section CD.

These forces are held in equilibrium by the stresses of tension and compression and shearing in the section CD. Taking the moments of all these forces about the neutral axis of the section, and noting that the moments of the shearing force and shearing stress are each equal to zero, as the direction of these forces passes through the neutral axis ; we have—

$$\frac{W}{2} \times n - \frac{Wn}{n + m} \times \frac{n}{2} = M \text{ (the moment of the tensile and compressive stresses).}$$

$$\therefore \frac{Wmn}{2(n + m)} = M$$

Now, the left-hand side of the equation attains its maximum value when mn is a maximum, that is to say, when $m = n = \frac{l}{2}$, *i.e.* when the plane of

section CD is at the middle of the length of the girder. Therefore, as the section of the girder is uniform throughout its length, M is a maximum, and consequently the intensity of the tensile and compressive stress is a maximum at the mid-girder section, at which place—

$$M = \frac{Wl}{8}$$

We can now proceed to apply the equation on page 194, connecting the intensity of the stresses with the moment of inertia of the section and the moment of the external forces, viz.—

$$\frac{p}{y} = \frac{M}{I}$$

In the present instance—

p is the greatest permissible stress = 5 tons per square inch.

y is the distance from the neutral axis at which this stress is exerted $= \frac{d}{2} = 3$ inches.

We have just proved that $M = \frac{Wl}{8} = \frac{W \times 10 \times 12}{8} = W \times 15$, and I is the moment of intertia of a rectangular beam about its neutral axis $= \frac{bd \times d^2}{12} = \frac{4 \times 6 \times 6 \times 6}{12} = 72$.

Hence we have—

$$\frac{5}{3} = \frac{15W}{72}$$

$$\therefore W = \frac{5 \times 72}{3 \times 15} = 8 \text{ tons}$$

The beam itself weighs 800 lbs., and therefore the additional load which it can carry evenly distributed is 7 tons 1440 lbs.

From what has been said regarding the variation of the intensity of the forces of tension and compression at different points of the cross-section of a beam according to the distance of the points from the neutral surface, it is evident that the solid square section is a very uneconomical one; for, while the outermost layers may be strained to the full extent considered advisable, the material towards the middle of the section is barely under any stress and consequently contributes nothing to the longitudinal strength.

Let us, therefore, rearrange the material in the section without altering its depth by taking away the shaded portions from the middle of the sides in Fig. 97 and putting the material thus gained in the top and bottom, as shown in Fig. 98 and then ascertain what evenly distributed weight the beam will bear under the same conditions as to maximum stress.

It will be noted that, as rearranged, the total area of the cross-section, and consequently the weight of the beam is unchanged.

The shape of cross-section obtained by the new arrangement of the material constitutes what is called a flanged girder, AB and CD being respectively the top and bottom flanges, while the middle portion which connects the flanges and holds them apart when under strain is called the web. In the present instance the flanges are each 8 inches wide and 1 inch thick, and the web is 4 inches deep and 2 inches thick.

The moment of inertia of this cross-section is easily obtained by deducting from the moment of inertia of a rectangle 8×6 inches, the moment of inertia of two rectangles, each 3×4 inches, all estimated about a common neutral axis.

The moment of inertia of the 8×6 inch rectangle $= \dfrac{8 \times 6 \times 6 \times 6}{12} = 144.$

" " " 3×4 " " $= \dfrac{3 \times 4 \times 4 \times 4}{12} = 16.$

The moment of inertia of the whole section $= 144 - 2 \times 16 = 112$. All the other elements of the calculation for the original beam remained unchanged. Hence we have—

$$\frac{5}{3} = \frac{15W}{112} \text{ (see page 194).}$$

$$\therefore W = \frac{5 \times 112}{3 \times 15} = 12{\cdot}44 \text{ tons.}$$

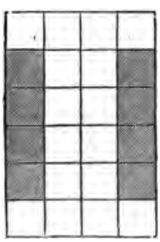

FIG. 97.

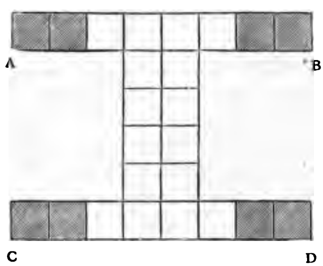

FIG. 98.

a result which shows that the carrying power of the beam has been increased over 50 per cent. by merely redistributing the material, while keeping the weight unchanged.

This illustration shows the great importance of properly studying the distribution of the material in a ship so as to obtain the requisite longitudinal strength on a given weight. Fortunately, the general form of a ship lends itself very considerably to the advantageous distribution of the material, especially when the upper deck is a continuous iron structure. In that case the iron deck and the sheer strakes of the hull plating correspond with the upper flange of the girder shown in

Fig. 98, while the iron bottom, together with the keel and other longitudinal beams, correspond with the lower flange. The more or less vertical sides answer to the web; for it is evident that the web in Fig. 98 can, without in the slightest degree altering the strength of the girder, or the moment of inertia of its section, be divided into two, and be rearranged as in Fig. 99. The flanged girder is thus changed into a box girder.

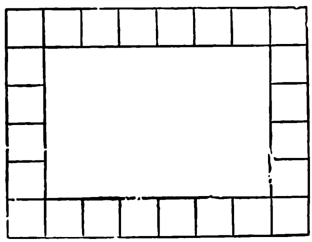

Fig. 99.

We shall now proceed to show the effect of altering the depth of the girder while keeping its weight unchanged. The alteration will consist n halving the thickness and doubling the height of the web, so that the cross-section assumes the form shown in Fig. 101.

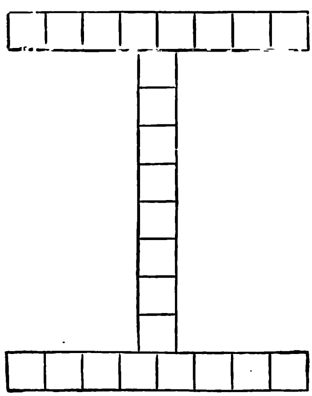

Fig. 100.

Apply the fundamental equation of page 192, viz.—

$$\frac{p}{y} = \frac{M}{I} \text{ or } M = \frac{pI}{y}$$

The dimensions which the cross-section have now assumed are $b=8$ inches, $d=10$ inches. The moment of inertia of the section is found, as before, by deducting the moments of two rectangles each 3·5 in. × 8 in., from the moment of a rectangle 8 in. × 10 in.

We thus obtain $I=370{\cdot}66$; and substituting all the other values as before in the equation $\frac{p}{y}=\frac{M}{I}$, we get $\frac{5}{5}=\frac{15\,W}{370{\cdot}66}$

$$\therefore W = 24{\cdot}71 \text{ tons},$$

as against 12·44 tons in the last and 8 tons in the first instance, that is to say, we have greatly increased the longitudinal strength of the original rectangular beam by redistributing its material without adding a pound to its weight.

From this result we see how the longitudinal strength of a ship is affected by the distances of the continuous iron deck and the bottom from the neutral axis.

It is also evident from the equation $\frac{p}{y}=\frac{M}{I}$ that the strength of the beam is, other conditiors remaining unchanged, directly proportional to the width of the section. Also as p increases with M, if the amount and distribution of the total load, including the inherent weight of the beam, remain unchanged, the intensity of the stress increases directly as the length, because M is always equal to a fraction of the weights multiplied by the length; in other words, the strength of the girder is inversely proportional to the length.

It will now be shown by a simple example how the theoretical principles regarding the stresses in beams are applied in estimating the strength of a given ship loaded in a particular way. It has already been shown how the bending moments due to the external forces may be computed and set out graphically. The internal stresses produced by the loads can be very readily obtained by regarding the ship as a beam, and making use of the fundamental equations for the strength of beams.

Although the cross-section of a ship is generally of a more, or less, complex shape and arrangement, it is easy to compute its moment of inertia directly from the section. Nevertheless, it is often advisable for the sake of illustration to deduce from the section what is called an equivalent girder section. Fig. 101 shows a sketch of the midship section of the mercantile steamer, the curves of weight, buoyancy, shearing forces, and bending moments of which have already been given in Figs. 90 to 93. Now, in this cross-section every piece of iron, whether it be skin, deck, or bottom plates, angle iron, longitudinal stiffener, keel, etc., which would be

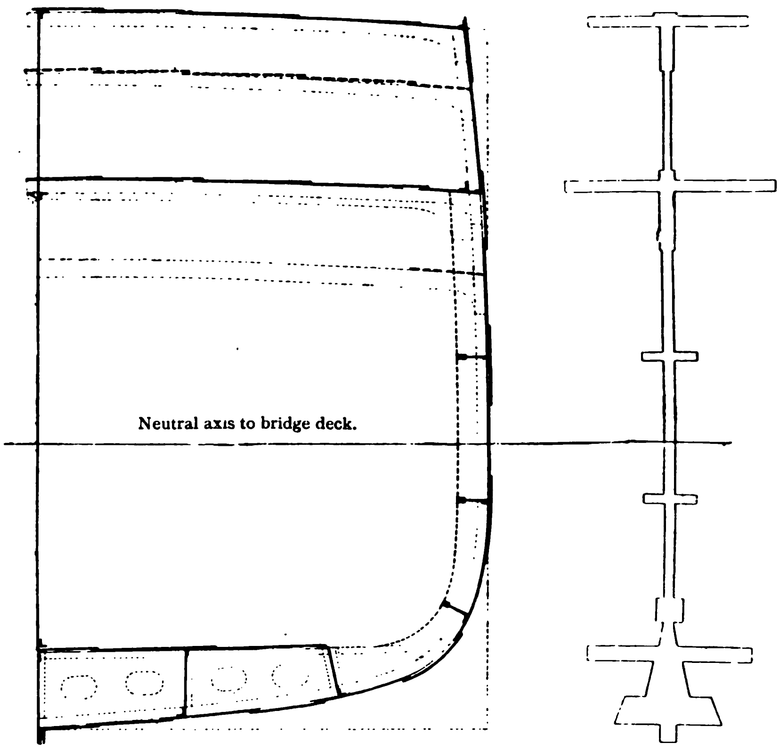

Fig. 101.

torn asunder if the vessel were to break in two pieces, contributes to the longitudinal strength in varying degree, according to its scantling and position relatively to the neutral axis. The equivalent girder shown alongside the midship section is merely a simple representation—approximating to the flanged girder form—of all the several areas of plating, etc., arranged in their proper positions relatively to the neutral axis. For instance, the top flange represents the total effective area of the bridge-deck plating. The larger flange below it represents in a similar manner the effective area of the main-deck plating. The two small flanges immediately above and below the neutral axis represent the areas of the longitudinals exactly on the same level as these in the midship section. The square piece next below corresponds to the area

of the longitudinal at the turn of the bilge and the curved skin plating adjacent. The thick flange next below is the equivalent of the inner bottom, the upper portions of the bottom longitudinals, including the keel and part of the curved bilge plating; the complex figure below it represents the area of the remainder of the bottom longitudinals and the bilge and bottom plating. The vertical web corresponds with the united effective areas of the side plating, and is wider at some places than at others, according as the skin plating is thicker or thinner. It will be noticed that the transverse frames and stiffeners and the deck beams do not enter into the equivalent girder section, as they contribute nothing to the longitudinal strength. The position of the centre of gravity, through which the neutral axis passes, may be found by computation, or more easily by cutting out the equivalent girder section drawn to a moderately large scale on thin cardboard, and by balancing the model on a knife edge.

In order to be quite accurate, separate equivalent girder-sections should be computed for hogging and sagging moments; because the effective areas of the parts under compression do not bear the same ratio to the gross areas of the same parts as they do when under tension. This arises from the allowance which has to be made in the two cases for the rivet holes. Take, for instance, the case of the skin plating. Where the latter is riveted to the transverse frames, lines of rivet holes are drilled, which diminish the area of the plates against a tensional stress, but do not diminish it against a stress of compression, provided the rivets thoroughly fill the holes.

When wooden deck-planking is used, it is allowed for, in drawing the equivalent girder section, as if it were equal to one-sixteenth part of the same area in wrought iron.

Having drawn the section of the equivalent girder, we can compute its moment of inertia in a somewhat simpler manner than that previously described.

In cases where the flanges are thin, relatively to the depth of the girder, each flange is supposed to be concentrated at its centre line, and the moment of interia is obtained by multiplying the area of the flange by the square of the distance of the centre line from the neutral axis of the whole section of the girder.

In the case of the web we have hitherto only considered cases in which the neutral axis of both the web and the entire section were coincident. In such cases the rule for obtaining the moment of inertia about the neutral axis of a rectangular area applied. In the present instance, however, the web is made up of many rectangles of different widths, and its neutral axis does

not coincide with that of the whole cross-section: we have therefore to estimate the moment of inertia of each of these rectangles, not about its own neutral axis, but about that of the entire cross-section. This operation is performed in the following manner:—

Divide the rectangle under consideration into a number of elementary horizontal strips of breadth b, and depth d, as before. Let the distance of a strip from the neutral axis of the rectangle be y, and the distance of this neutral axis from that of the entire section be y_1, a fixed quantity. Then the moment of inertia of the strip under consideration about the neutral axis of the entire section equals the area of the strip multiplied by the square of its distance from this neutral axis—

$$= bd\,(y + \mathrm{y}_1)^2$$

and the moment of inertia of the whole rectangle equals the sum of the moments of the separate strips—

$$= \Sigma\, bd\,(y + \mathrm{y}_1)^2 = \Sigma\, bd\,(y^2 + 2y\mathrm{y}_1 + \mathrm{y}_1^2)$$
$$= \Sigma\, bdy^2 + 2\mathrm{y}_1\,\Sigma\, bdy + \mathrm{y}_1^2\,\Sigma\, bd.$$

Now of these three terms, the first, Σbdy^2, is the expression for the moment of inertia of the rectangle about its own neutral axis; the second term equals zero, because it contains a factor Σbdy, which must equal zero, because the neutral axis of the rectangle passes through the centre of gravity of the rectangle, while the third factor, $\mathrm{y}_1^2\ \Sigma bd$, represents the area of the rectangle multiplied by the square of the distance between the neutral axis of the rectangle and that of the entire section. The same reasoning would apply to an area of any other shape; hence we obtain the following very simple rule for estimating the moment of inertia of an area about any axis parallel to its own neutral axis—

$$\mathrm{I} = \mathrm{I}^\circ + \mathrm{A}\,\mathrm{y}_1^2$$

Where I° = moment of inertia of area about its own neutral axis;
I = ,, ,, ,, ,, ,, ,, a parallel axis;
y_1 = the distance between the two axes;
A = the area of the figure in question.

We have already given the values of the moments of inertia of certain elementary geometrical figures, such as rectangles, and triangles about their own neutral axis, and by substituting the appropriate one of these values for I° in the above formula and giving to y_1 the number representing the distance between the two axes, we obtain the numerical value of the moment of inertia of the given area about the neutral axis of the entire cross section.

By means of the above considerations it is quite easy to compute the moment of inertia of any cross section of a ship, and when this and the position of the neutral axis are obtained, the stress at any part can be calculated by means of the formula given on page 192.

$$M = \frac{p}{y} I.$$

For instance, suppose the bending moment M = 38000 foot tons.
the moment of inertia I = 177500
the distance of upper deck from neutral axis y .. .. = 17 ft. 9 in.

then the stress per square inch in upper deck $p = \frac{38000 \times 17{\cdot}75}{177500} = 3{\cdot}8$ tons.

As might be expected, the maximum stresses experienced at sea by vessels vary very largely with their dimensions. The late Mr. W. John, of Lloyd's Registry, carried out, as far back as the year 1873, a series of calculations on the stresses of iron ships of different sizes when exposed to hogging strains on waves of about their own length. The results were communicated to the Institution of Naval Architects.* The scantlings were, as nearly as possible, those adopted for first-class vessels. The type of construction was what is known as the transverse system of framing. The vessels were not provided with iron decks, the longitudinal strains having been met principally by the upper and lower portions of the shell plating, by deck stringers and by longitudinals laid along the bottom and bilges. In this respect, they differed very much from the modern system of construction, exemplified by the vessel the cross section of which was given on page 198.

The general proportions of the vessels investigated were as follows —breadth equal to one-eighth of length, and depth equal to one-eleventh of length. The following table gives the maximum tension on the upper works under the conditions set forth :—

Tonnage of Vessels.	Maximum tension on upper works in tons per sq. inch.	Tonnage of vessels.	Maximum tension on upper works in tons per sq. inch.
100	1·67	800	4·59
200	2·30	900	4·8
300	3·09	1000	5·19
400	3·55	1500	5·34
500	3·95	2000	5·9
600	3·72	2500	7·08
700	4·57	3000	8·09

A glance at these figures is sufficient to show what a serious problem the proper provision of longitudinal strength became in vessels built

* *Transactions, Institution of Naval Architects*, vol. xv. p. 74.

on the old system after they passed the limit ot about 2,500 tons displacement. It will be a very useful study for the reader to compare the figures given in Mr. John's table with the results of the calculations for the well-decked vessel of modern construction, having steel and iron decks, a double steel bottom, with continuous longitudinals between them and continuous longitudinal side-stringers, shown in cross section on Fig. 101. The load displacement was 4,940 tons, or nearly two-thirds greater than that of the largest vessel given in Mr. John's table. The length of this vessel was 290 feet. The maximum tensile stress on the upper works under a hogging strain was exerted when the vessel was loaded with a homogeneous cargo, with the bunkers full, and poised on the crest of a wave of her own length. Under these circumstances, the stress only reached 4·46 tons per square inch. When loaded with a cargo of iron ore, concentrated amidships and on the hollow of a wave, the maximum compressive strain on the upper works reached 7·2 tons per square inch.

Before leaving this subject two points should be mentioned. In all that has hitherto been written concerning the strength of ships it has been taken for granted that the structure of the vessel, where it comes under compression, is stiff enough to take the stress without undergoing change of shape. If, for instance, an iron deck when undergoing compression were to pucker, or crumple through lack of rigidity, the portions which thus changed their shape could not possibly take their proper share of the stress, and the result would be that the stiffer portions, such as those immediately supported by the skin of the ship, would take more than their fair share, and might, consequently, break down although the deck, as a whole, neglecting the question of rigidity, possessed an ample section of metal. Cases have been known in which vessels have broken in two at sea, although the theoretical calculations showed that the deck, considered as rigid, was not severely compressed. The case of the ss. *Mary* (*see* p. 181), which broke in two in the Bay of Biscay when steaming across waves of about her own length, is an instance in point. This vessel was of light draught, and was intended for service in shallow waters abroad, and was overtaken by disaster when proceeding to her destination. When her ends were supported on the crests of waves of her own length she underwent a sagging moment sufficient to put the deck, if rigid, under a compressive stress of about nine tons per square inch. Now, it is considered that this stress, though very severe, was not sufficient of itself to have caused the fracture of the vessel. The calculations of Mr. John, previously referred to, make it appear probable that many vessels of over 3,000 tons displacement built on the old system, must have occasionally undergone a similar stress with impunity. In the case of the *Mary*, however, the *iron deck* was so deficient in rigidity that it could not transmit a

greater compressive stress than three tons per square inch without buckling, and "was able at all times to evade taking a higher strain so long as any other portion of the deck of the ship was sufficiently rigid to relieve the deck plating of the extra strain."* The side plating began to buckle when the compressive stress exceeded about four tons per square inch, and the sheerstrake behaved in a similar fashion when five tons per square inch was exceeded. The result was that an excessive stress, estimated at about sixteen tons per square inch, was thrown on the gunwale angle iron and the portions of the deck and sheerstrake immediately adjoining it. Under this stress the material gave way and the vessel broke in two.

The other point to which attention should be given is the effect on the curve of buoyancy, and consequently on the curve of bending moments, of the internal structure of the wave. Hitherto, when considering the effect on the bending moments of the passage of the vessel through waves of its own length, it has been taken for granted that the local alteration in the distribution of buoyancy was exactly equal to the corresponding alteration in the distribution of displace ment. This, however, is far from being the case, for in a wave the particles are all in motion, and the effect on the buoyancy of a body floating in them is not the same as it would be were the particles at rest. It is not possible in an elementary work to go fully into the reasons for this phenomenon. It can only now be stated generally that, at the top of the wave, the alteration of the buoyancy of a floating body is less, and at the bottom of the wave it is more, than what would be due to the displacement. Consequently the actual form of the curve of buoyancy is greatly affected by the draught of the vessel entering the waves. The greater the draught the less the effect of the wave in altering the distribution of the buoyancy, and *vice versâ*. The result of not taking account of the above phenomenon is that the maximum bending moments are often largely over-calculated. In the case of a vessel of very fine form, both as regards water lines and rise of floor, and having a mean draught of eighteen feet, it was found that the sum of the maximum hogging and sagging moments, when calculated, without allowing for this peculiarity of the wave structure,† was about 45 per cent. greater than the true figure. This is a very considerable error, and may possibly account to some extent for the

* See *Transactions of the Institution of Naval Architects*, vol. xviii. page 104, paper entitled "On the Strains of Iron Ships," by Mr. W. John.

† See *Transactions of the Institution of Naval Architects*, vol. xxiv. p. 135, paper entitled "On the Hogging and Sagging Strains in a Sea Way as influenced by Wave Structure," by Mr. W. E. Smith.

severe stresses attributed by the late Mr. W. John to large vessels when passing through waves of their own length.

It is not necessary, in a handbook of this character, to go further into the theoretical considerations affecting the strength of ships. Enough has already been said to explain the principal elementary considerations which should guide a shipbuilder in the distribution of his material, so far as he is free to distribute it for the purpose of securing longitudinal strength. It has, however, been already pointed out that the structure of a ship has to fulfil many purposes and in many different positions, and that, consequently, the shipbuilder's problem is a much more complex one than that of the bridge builder, or architect, and he is not free to distribute his material merely with a view to its resisting general longitudinal strains. He has also to provide for the transverse stresses, for the accommodation of cargo, for the safety of the ship if it be pierced by collision, or when taking the ground, and also for the many local strains which occur: and he has, furthermore, to make sure that, when a ship is rolling at sea, with its deck and bottom frequently occupying an inclined position, it shall still be strong enough to withstand any strains brought to bear upon it. From most of these anxieties the iron bridge builder is free. The general longitudinal strains are by far the most important which the latter has to provide against, hence he can pile his material in the top and bottom flanges of his girders, leaving the web merely strong enough and stiff enough to withstand the shearing stresses. In fact, in the majority of cases he reduces the web to a lattice structure. He is seldom limited by local considerations in fixing the depth of his beams: his principal external forces act in fixed directions, and their amounts can generally be exactly foreseen and provided against. The shipbuilder, on the other hand, can never reduce the sides of his ship, which correspond to the web of a girder, down to the theoretical minimum required to transmit the shearing stresses; the sides must be continuous iron structures heavily stiffened to withstand the water pressure and the rough wear and tear to which a ship is subjected. Moreover, as has been already pointed out, when a vessel rolls, the sides partially assume the positions and have to fulfil the structural purposes of the top and bottom, and are subjected to severe bending moments. The shipbuilder is also generally limited, in fixing the depth of his vessel, by local considerations, such as the available depth of water in harbours and docks. It has been shown before that, owing to the effect of the waves in altering the distribution of the buoyancy of the vessel, the amount and the direction of the stresses brought to bear on the structure are constantly varying. From all the above considerations it is evident that the shipbuilder, in combining the several parts of his structure, and in determining the scantlings, must largely be guided by experience as well as by theory.

APPENDIX II.

TONNAGE AND ITS MEASUREMENT AT DIFFERENT TIMES.

THE meaning of the word "tonnage" as applied to ships requires some explanation, as the word had different significations at different periods and even at the present day is used in various senses. An explanation will be given, firstly, of the various meanings of the term as applied to mediæval and to modern wooden sailing-ships from the commencement of the fifteenth century down to our own times, and, secondly, to steam ships. A short account will also be given of the operation of the most important tonnage laws and of their effect upon the designs of ships.

The word originally referred to the capacity of a vessel to hold tuns of wine. There is a letter in existence in the Cottonian collection of manuscripts, in which the Spaniards offered to sell to Henry V. two carracks of the tonnage of 1400 and 1000 butts respectively. Even without this distinct reference to wine barrels there is strong evidence to show that the capacity of a tun of wine was the unit referred to when the tonnage of a ship was mentioned in mediæval works, and that it even survives to this day in the mercantile marine. By an Act of Parliament passed in the year after Henry V. died it was enacted that the tun of wine was not to measure less than 252 gallons old English measurement, and it still measures exactly the same quantity. Now, a cubic foot measures 6¼ gallons, and therefore the internal capacity of the tun was 40·32 cubic feet. If we add to this the cubic contents of the shell, the total capacity of the tun could not have been less than 42 cubic feet. Now, this figure, or one closely approximating to it, appears to have been used in one form, or another, in connection with a ton of shipping down to the present day. Two hundred and fifty years after the death of Henry V., in 1687, we find that the Ordonnance de la Marine of Louis XIV. fixed the ton of shipping as being a capacity of 42 cubic feet, and at the present day there is a measure called the "freight ton," which is in common use among shippers, and which has the capacity of 40 cubic feet.

We may therefore very reasonably affirm that the word ton, as applied to shipping in the time of Henry V. and for long after, meant the capacity to hold a barrel measuring 42 cubic feet, in the hold below deck, and that, therefore, when we read of a vessel of, say, 900 tons, we are to understand a capacity, under deck, to hold 900 such

barrels. Inasmuch as the barrels were circular in cross section, and as they could not be packed closely into all the parts of the hold, on account of the curved shape of the hull, we may reckon that, in order to arrive at the total internal capacity of the hold of one of these old ships, we should increase the number of cubic feet in the barrels by at least one-third. Thus, the vessel of 900 tons would have a cubic capacity of hold at at least $\frac{900 \times 42 \times 4}{3} = 50{,}400$ cubic feet; or 56 cubic feet to the ton. The weight of wine contained in one of these tuns was about 12 per cent. over a ton avoirdupois.

In the early part of the seventeenth contury there appears to have been no standard rule for computing the tonnage of English ships. Charnock points out that, during the great part of that century, the mode of calculating tonnage was more indeterminate than can readily be credited. He states that the *Royal Sovereign*, when first launched, was, according to her builder's calculation, of 1637 tons burthen. In a MS. list of the Navy of 1651 she is described as of only 1141 tons, while in 1654 the tonnage is increased to 1556. He also remarks that "the same variation takes place uniformly through all the ships of the Navy, and fully proves that the calculations alluded to were founded on little more than mere supposition."

Towards the end of the seventeenth and in the early part of the eighteenth centuries the tonnage of warships was commonly computed in the following manner. The length of the keel was multiplied into the extreme breadth within board, taken along the midship beam. This product was multiplied by the depth of the hold from the plank, joining the keelson upwards to the main deck, and the last product divided by 96; the result gave the tonnage.

In 1719 the Lords of the Admiralty adopted a very complicated rule for obtaining the length of the keel for tonnage. This length, multiplied by the breadth, and the product by the half breadth, and the last product divided by 94, gave the tonnage approximately.

In 1694 an Act was passed for measuring the tonnage of English merchant ships, which contained the following rule :—

$$\text{Tonnage} = \frac{L \times B \times D}{94}$$

When L = length of keel (so much as she treads on the ground).
B = breadth amidships from plank to plank, in board.
D = depth of hold, as before.

The result of the above formula was supposed to give the *dead weight* carrying capacity of the vessel.

The product $L \times B \times D$, of course, expressed the parallelopipedon of which the sides were, the length of keel, the breadth in board from plank to plank, and the depth of hold, and the divisor 94 meant that every 94 cubic feet of this parallelopipedon was to be reckoned as one

ton. As the true internal volume of the vessel would not exceed six tenths of that of the parallelopipedon, it is evident that about $(94 \times 6) \div 10 = 56{\cdot}4$ cubic feet was reckoned as a ton, and this figure approximated fairly to the value in the time of Henry V.

The Act of 1694 was repealed two years later, and in 1720 another was passed, which substituted the half breadth for the depth of hold. Probably no Act has ever done more injury to naval architecture than the tonnage law of 1720. The half breadth, no doubt, at the time, represented very approximately the depth of hold; but the law offered a direct inducement to shipbuilders to augment the carrying power of their vessels, without altering the legal tonnage, by the simple expedient of increasing the depth while making no corresponding increase in the breadth and length, and thus a class of short, narrow, deep, and utterly unseaworthy vessels came into existence.

The celebrated Tonnage Act of 1773, which remained in legal force for sixty-two years, and which was still in use in the Royal Navy till as lately as 1872, perpetuated the same error. The tonnage, as measured under this Act, was called Builders' Old Measurement Tonnage. The length for tonnage under this Act was measured along the rabbet of the keel, from the back of the sternpost to a perpendicular dropped from the fore part of the main stem, under the bowsprit. From the length thus obtained, a deduction equal to three-fifths of the breadth (measured as below explained) was allowed, and the difference was called the length for tonnage. If the vessel were afloat at the time of measurement, instead of taking the length along the keel, the length of waterline, or of deck, was ascertained, and an allowance made, by way of reduction, of 3 inches for every foot of draught. This allowance was to compensate for the rake of the sternpost, and was independent of the deduction of three-fifths of the breadth. The breadth was measured outside the planking at the widest part of the ship, but the thickness of any doubling strakes was not included. Half of this breadth was taken instead of the depth. Subject to these allowances and differences in the mode of measurement, the B.O.M. tonnage law was identical with that of 1720, the divisor 94 having still been used.

In 1836 the mode of measuring ships was again legally altered, and the so-called "New Measurement" system was adopted and remained in force till 1854. The object of the "New Measurement" Act was to obtain a more accurate computation of the cubic contents of those parts of a vessel available for stowage, underneath the permanent decks. The depth was restored as an element in the calculation, but the various lengths, depths, and beams were to be measured at *a very few fixed positions*, and this peculiarity of the Act offered owners many opportunities of evading the intention of the law. It is said that in some cases ships built under this Act had a volume of about one-sixth greater than their nominal capacity. The factor for division

was 92·4 instead of 94, and in the case of steamships the volume of the space between the engine-room bulkheads was allowed as a deduction from the gross tonnage. The general effect of this Act was to do away with the premium which previous legislation had offered to the building of short, narrow, deep ships; but, on account of the many opportunities which it offered for evasion, it was eventually superseded by the Moorsom system of measurement, which became law in 1854, and, though subsequently amended in detail, remains to this day the basis for the computation of tonnage in all the principal nations of the world.

The object of the Moorsom system, like that of 1836, was primarily to effect a more accurate calculation of the cubic capacity of the permanently closed-in spaces of the ship. It is not necessary here to go into the details of the system. It is sufficient to say that the length is measured along the "tonnage deck," from the stem to the stern-post, and this length is divided into a certain number of equa parts, varying from four in ships below 50 feet in length to twelve in vessels of 250 feet and upwards. At each of these points the area of the cross-section below the tonnage-deck is calculated, and from these and the corresponding lengths the cubic capacity is found. The tonnage-deck is defined as the upper deck in all vessels having less than three, and the second from below in those having three or more decks. The capacity of the space between the tonnage and the under side of the upper deck is also measured, and also that of any permanently closed-in spaces on the upper deck available for cargo, stores, or for passengers and crew. The total thus obtained is divided by 100, and the resultant figure is called the "Gross Tonnage." In other words, a unit of gross tonnage means a volume of 100 cubic feet of permanently closed in space in a ship measured as above explained.

In order to arrive at the net or "Register Tonnage," the following deductions are allowed from the gross tonnage. In the case of sailing vessels, any space used exclusively for the storage of sails, provided it does not exceed 2½ per cent. of the tonnage; any spaces used exclusively for the accommodation and feeding of the crew, for the accommodation of the master, for the steering, the capstan, the anchors and their gear, the charts, instruments of navigation, and boatswain's stores, hatchways up to ½ per cent. of the gross tonnage, shelters for deck passengers approved by the Board of Trade; also the space occupied by the donkey-engine and boiler, provided that this engine can work the main pumps of the ship.

In the case of steamers certain other deductions are allowed for the spaces solely occupied by the machinery or necessary for its working. In the earlier tonnage laws as applied to steamers the whole of the contents of the ship bounded by transverse vertical planes passing through the fore and aft ends of the engine-room were deducted from the gross capacity as measured under the various Acts. Under the

Act of 1854 the actual cubic capacity of the space necessary for, and solely occupied by, the machinery and boilers is measured and, in the case of *paddle steamers*, if this cubic space is between 20 and 30 per cent. of the gross capacity then 37 per cent. of the gross tonnage is deducted. If the engine- and boiler-room space is less than 20 or more than 30 per cent. of the gross, then 50 per cent. more than the actual measured space is deducted.

In screw steamers the deductions are different. If the engine- and boiler-room space is between 13 and 20 per cent. of the gross, then 32 per cent. is deducted from the gross tonnage; but if it is below 13 or above 20 per cent. then 75 per cent. more than the actual space as measured is deducted.

In addition to the above allowances for engine spaces, deductions are also made as already described in the case of sailing ships, except that nothing is allowed for the space reserved for stowage of sails, and that no deductions may nowadays be made for any spaces unless they have first been measured into the gross.

The object sought in adopting this system of percentage deductions was to give steamers the same allowance as under the older method and, at the same time, to check an abuse, which was occasionally practised under the old method, of obtaining too large a deduction by unduly increasing the length between the engine-room bulkheads. The rules, however, did not give satisfaction, and they were superseded in the year 1860 by fresh regulations which aimed at deducting from the gross the tonnage of the whole section of the ship between the engine-room bulkheads, precautions having been taken to nullify any advantage sought to be gained by placing these bulkheads too far apart. After having been in operation for six years the validity of these rules was contested in a court of law, and a decision adverse to the Board of Trade having been given, they were withdrawn.

Various abortive attempts at fresh legislation were made after the year 1866, but it was not till 1889 that an Act was passed which altered the method of measurements for engine-room spaces. It should be mentioned, however, that in the year 1873 an International Commission met at Constantinople to frame rules for the tonnage measurements of steamers using the Suez Canal, and these rules have been in force, for this particular purpose, ever since.

In the year 1880–81 a Royal Commission was appointed to inquire into the whole subject of tonnage measurements and certain recommendations relating to the deductions for propelling spaces in steamers were adopted and introduced into the Merchant Shipping Bill of 1884, but failed to pass.

The Act of 1889 enacted that no deduction shall be allowed in respect of any space which has not been first included in the measurement of a vessel's gross tonnage. This was done in consequence of

a legal decision which the London & North Western Railway Company had obtained in the year 1879, in respect of their steamer the *Isabella*, under which the Board of Trade were compelled to include in the engine room space to be deducted from the gross tonnage, the contents of engine room skylights and boiler casings above the upper deck, although these spaces had not been measured into the gross.

The following addition was made to the Act of 1854, viz.:

> "Such portion of the space above the crown of the engine-room and above the upper deck as is framed in for the machinery or for the admission of light and air shall not be included in the measurements of the space occupied by the propelling power, except in pursuance of a request in writing to the Board of Trade by the owner of the ship, but shall not be included in pursuance of that request unless—
>
> "(*a*) that portion has first been included in the gross tonnage;
>
> "(*b*) a surveyor of ships certifies that the portion so framed in is reasonable in extent and is so constructed as to be safe and seaworthy, and that it cannot be used for any purpose other than the machinery or for the admission of light and air to the machinery or boilers of the ship."

In the year 1894 an Act was passed which simply consolidated, without making any changes in the previous Acts.

The methods of carrying out the Acts are contained in the printed instructions of the Board of Trade relating to the measurement of ships.

The methods of calculating gross and net tonnage adopted by the United Kingdom are also in use in the United States, Austro-Hungary, Germany, France, Netherlands, Norway, Russia and Japan, and with slight variations in most other countries; but it is illustrative of the variety of ways in which the Act may be interpreted that British vessels sold, say to France, have quite different tonnages assigned to them by the French authorities to what they had before they were sold.

The Tonnage Acts are of vast importance to shipowners, because all persons or bodies, such as harbour boards, which are authorised to charge dues on shipping have (in the absence of special Acts of Parliament providing for a different arrangement) to levy these dues on the net registered tonnage. Under the Acts it is possible, by slight differences in the design, to make very large differences in the net registered tonnage. Some of the causes of this peculiarity of the Acts will presently be explained. The dues charged on shipping are amongst the heavy working expenses. Hence, to take advantage of the Acts so as to reduce the net register of a ship relatively to its gross tonnage, or to reduce the gross itself, are considerations which are always present in the minds of shipbuilders, and necessarily exercise an enormous

influence on design. This must be regarded as a most unfortunate circumstance, because the design of ships should be governed by purely physical considerations relating to the circumstances peculiar to the particular trades for which they are intended and should not be complicated by fiscal questions. While many of the methods employed to reduce the net registered tonnage relatively to the gross are perfectly harmless from the point of view of the safety of the ships, some of the methods of reducing the gross in a ship of given size are far from being so; hence the tonnage laws in some respects put a premium on insecurity. This influence is by no means peculiar to the existing laws. It was at work long before the days of steamers and of tonnage deductions, and was in these days due to faulty methods of measuring capacity. Some of the evil effects of the Acts of 1720 and 1773 which substituted the half breadth amidships for the depth have been pointed out above. Another effect produced by these Acts was that, at one time, in order to secure as small as possible a breadth where the measurement was taken, vessels were constructed with narrow waists and were increased in width fore and aft of the midship section. A certain Mr. Riddle was connected either with the framing of the Act, or its administration. The effect of his work on ship design has been handed down to posterity in the following lines:—

"Ships measured by Riddle,
All shaped like a fiddle,
And improvements fiddle-de-dee."

Not much fault can be found with the system of measurement embodied in Moorsom's Act. The anomalies that have arisen have been due to the interpretation of the term "permanently closed-in spaces" that have to be measured into the gross, and in the operation of the deductions that are allowed in respect of engine-room and other spaces.

The interpretation of the Acts is entrusted to the Board of Trade, and there have been frequent disputes as to what spaces shall be measured into, or excluded from, the gross tonnage. For instance, the double bottoms of water-ballast ships and the peak and other ballast tanks have been the subject of such disputes. At first the Board of Trade contended that a portion of the cubic contents of double bottoms should be included in the gross tonnage; but this question was finally settled in favour of shipowners. The peak tanks are, under certain conditions, not included in the gross measurement, neither are the high wing ballast tanks of Dixon and Harroway's system (*see* page 122), nor the side tanks of McGlashan's system (*see* page 122), so included.

In cross-Channel steamers great reductions are often made in the gross measurement by such devices as leaving openings in decks; not carrying water-tight bulkheads to the upper deck; leaving open

the entrances into spaces below top-gallant forecastle decks. The spaces thus treated are not counted as permanently closed-in, and hence they escape measurement; but it cannot be denied that the safety of these vessels at sea would be greatly increased if these spaces were closed in, and this is an instance in which the Tonnage Acts produce a premium on imperfect sea-worthiness.

The case of cross-Channel steamers is somewhat peculiar. Vessels have to pay dues every time they enter a port, and as steamers engaged on this class of service have generally to enter two ports daily, the annual charge for dues would be very large if the net registered tonnage were not kept down by every available means. In some cases the net tonnage is as low as one sixth of the gross, and ratios of one to three and one to four are quite common. It is, however, not the ratio to the gross but the actual amount of the net tonnage which is of most importance to the owners, and this amount is kept low not only by reducing the gross in the manner indicated above, but by taking full advantage of the rules for deductions. If these rules be studied it will be seen that a difference in the type of the propelling machinery and a quite small difference in the space actually occupied by it, may make a very large difference in the total deduction permissible.

As an illustration of the curious results produced in estimating net tonnage mention may be made of the case of three steamers A, B and C, of the shelter-deck class, of the same dimensions, and the same general arrangement, but differing in certain details, such as the size of engine-rooms, in respect of which deductions would be made. The following were the gross and net tonnages actually arrived at.*

Gross.	Net.	Ratio of gross to net.
A.—949	493	1·924
B.—951	401	2·371
C.—952	371	2·566

Mr. James Maxton of Belfast has mentioned an equally curious case of a steamer in which the gross tonnage was affected, owing to the fine line drawn between spaces that are measured, or exempted, as closed in. In the vessel in question, by the fitting of some hatch cleats and closing a few scuppers the gross tonnage, on the same moulded dimensions, would have been increased from 1,100 to 1,750 tons.†

* Paper by Mr. A. G. Ramage, entitled "Minimum Net Register and its Effect on Design." *Transactions of the Institution of Naval Architects*, vol. xl.

† Paper by Mr. James Maxton entitled "Registered Tonnages and their Relation to Fiscal Changes and Design." *Transactions of the Institution of Naval Architects*, vol. xiv.

From the foregoing it is apparent that gross tonnage cannot be taken as a measure of the size of ships, and that net tonnage bears no relation to dimensions, capacity, or earning powers. It has been shown that the law as it stands sometimes unfavourably affects the sea-worthiness of ships. Even from the statistical point of view, the figures which represent gross and net tonnage, bearing as they do no definite relation to size, are perfectly valueless. Dock and harbour authorities look upon the laws from a totally different standpoint to shipowners; but they also naturally complain of a system which permits such gross anomalies as have been mentioned above.

The displacement system of tonnage is at present universally applied to warships. The term "displacement" means the weight of water displaced by the ship at any particular draught, which, of course, exactly equals the total weight of the ship and its contents at the draught in question. As 35 cubic feet of sea-water equal 1 ton, the cubic capacity in feet of the immersed portion of the vessel equals the displacement in tons multiplied by thirty-five.

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